CECW-EH Engineer Manual 1110-2-1413	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	EM 1110-2-1413 15 January 1987
	Engineering and Design HYDROLOGIC ANALYSIS OF INTERIOR AREAS	
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DEPARTMENT OF THE ARMY
U. S. Army Corps of Engineers
Washington, DC 20314-1000

EM 1110-2-1413

DAEN-CWH-Y

Engineer Manual
No. 1110-2-1413

15 January 1987

Engineering and Design
HYDROLOGIC ANALYSIS OF INTERIOR AREAS

1. Purpose. This manual provides guidance and criteria for hydrologic analysis of interior areas. An interior area is defined as the area protected from direct riverine, lake, or tidal flooding by levees, floodwalls or seawalls and low depressions or natural sinks.

2. Applicability. This manual is applicable to all Civil Works field operating activities concerned with planning and design of interior flood control systems.

3. General. This manual provides information of interest to planners and designers of interior systems involving flood loss reduction measures and actions. Interior area investigations are differentiated from other studies only by the uniqueness of the hydrologic analysis requirements for the flood loss reduction measures commonly studied. Interior area planning studies are an essential aspect of feasibility studies. Although facilities and costs may at times be small components of a major line-of-protection project, the elements are often major items in the negotiated local sponsor agreements and can represent a significant proportion of local costs.

FOR THE COMMANDER:

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Colonel, Corps of Engineers
Chief of Staff

DAEN-CWH-Y

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CHAPTER 1

INTRODUCTION

1-1. Purpose and Scope.

The purpose of this document is to provide guidance in hydrologic analysis of interior areas for planning and design investigations. The document was developed to satisfy needs expressed by Corps of Engineers field offices for procedural and technical guidance in performing hydrologic assessments of interior areas.

1-2. Interior Systems.

a. An interior area is defined as the area protected from direct riverine, lake, or tidal flooding by levees, floodwalls or seawalls and low depressions or natural sinks. Figure 1.1 is a conceptual illustration of an interior area and attendant physical works. The levee or wall associated with an interior area is generally referred to as the line-of-protection. The line-of-protection excludes flood water originating from the exterior but normally does not directly alleviate flooding that may subsequently occur from interior runoff. In fact, the line-of-protection often aggravates the problem of interior flooding by blocking drainage outlets. Protected interior areas, formerly flooded from the river (lake or coastal area) by slowly rising flood waters generated from regional storms, may now be subject to flooding from events that are more localized, occur more suddenly, and provide less prior warning. The flooding may be aggravated by coincident high river, lake, or coastal stages. The interior flooding that results may be of the nuisance variety (shallow, temporary flooding) but can be in an extreme case as dangerous (or more so) as the situation without the levee.

b. Interior flood waters are normally passed through the line-of-protection by gravity outlets when the interior water levels are higher than water levels of the exterior (gravity conditions). The flood waters are stored and/or diverted and pumped over or through the line-of-protection when exterior stages are higher than that of the interior (blocked gravity conditions). Gravity outlets, pumping stations, interior detention storage basins, diversions and pressure conduits are primary measures used to reduce flood losses within interior areas. Other structural and nonstructural measures, such as reservoirs, channels, flood proofing, relocations, regulatory policies, and flood warning-emergency preparedness actions, may also be integral elements of interior flood loss reduction systems.

c. Interior areas are studied to determine the specific nature of flooding and to formulate alternatives that enhance the national economy, and secondarily enhance the environment, social well being, and regional development. The selected plan for implementation is the one that best meets these objectives.

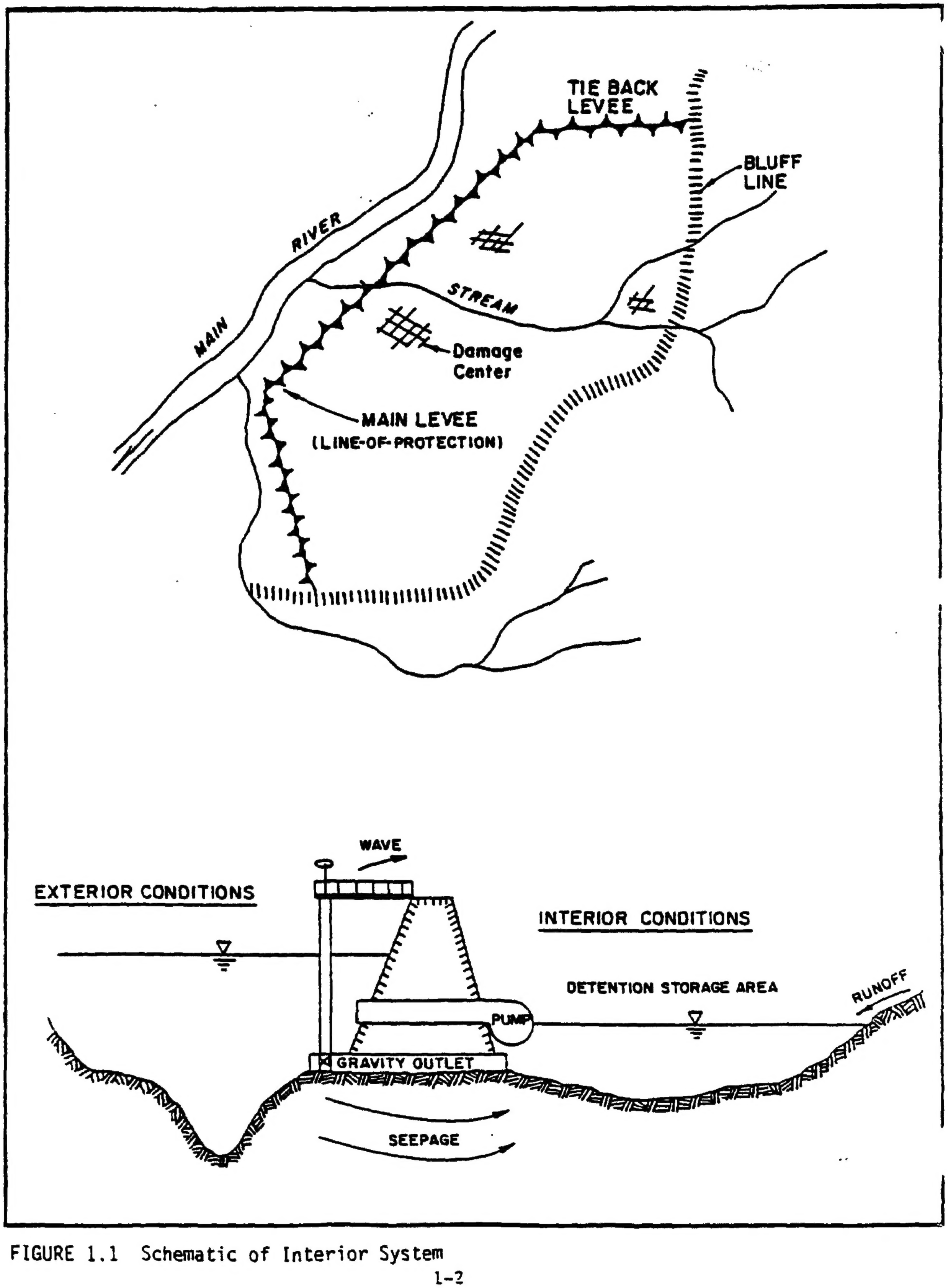


FIGURE 1.1 Schematic of Interior System

d. Hydrologic analysis of interior areas is complex because of interior flooding combined with uncertainty of stages on the exterior side of the line-of-protection. The investigation is often difficult. Records may be scant or nonexistent, land use (and thus runoff) may have changed from the past and is often continuing to change, natural drainage paths have been altered, and coincident flooding (a technically complex subject) is the common situation. Areas are generally small (less than 10 mi^2 though some are much larger) and the measures that should be considered are numerous.

e. Interior area investigations are differentiated from other studies only by hydrologic analysis factors and the uniqueness of commonly implemented flood loss reduction measures. The study process and types of studies conducted to plan and design flood loss reduction actions are identical to those of other investigations. These studies include planning investigations, survey reports, and other forms of feasibility studies, design studies (General and Feature Design Memoranda), and similar studies for small projects under continuing authorities. Analysis of interior areas is relevant to formulation and evaluation procedures, level of protection considerations, and hydrologic, economic, environmental, and social assessment criteria as established by present federal planning and design policies and regulations.

f. Interior area planning studies are an essential aspect of feasibility studies. Although facilities and costs may at times be small components of a major line-of-protection project, the elements are often major items in the negotiated local sponsor agreements and can represent a significant proportion of local costs.

1-3. Interdisciplinary Study Requirements.

a. The present precept of planning is that it be conducted by an interdisciplinary group performing their studies in an open public participation environment. Corps guidance states:

> "An interdisciplinary approach is to be used in planning to ensure the integrated use of natural and social sciences . . ." (Reference 7).

b. The hydrologic engineer is a participating member of an interdisciplinary study team that typically includes representatives from economic, environmental, social, and engineering disciplines. The study is normally coordinated by a study manager who is also a team member. Continued interface with these and other participants is required since results must be compatible with needs for performing flood damage, cost, environmental, social, and other assessments. An important early task for the team is to tailor the investigation to the problems and needs of the study area under investigation. Important issues, concerns, and study conduct will be defined and a procedure for continuing coordination among participants will be prepared and adopted. Integration of hydrologic information with this range of interdisciplinary study requirements reflects the importance of developing reliable study estimates. Hydrologic strategies and analysis procedures

developed are dependent to a large degree on these study requirements. Therefore, close coordination and continuous communication with other disciplines is essential, from the initiation of the study through final decisions. The hydrologic engineer is responsible for participating (taking the initiative if necessary) in needed study coordination for activities that are related to hydrologic engineering.

1-4. Organization of Manual. This manual is designed to provide guidance for hydrologic studies associated with the planning and design of flood loss reduction measures for interior areas. Emphasis is on the interface of hydrologic studies with elements involved in planning investigations. Most hydrologic studies are conducted to provide technical data for formulating and evaluating solutions to flooding problems. The manual sets forth pertinent requirements and defines the commensurate hydrologic study needs. It provides chapters on: a description of the general study process, progressing from feasibility through feature design investigations; an outline of basic hydrologic assumptions and strategies for performing the studies; and a description of available hydrologic analysis procedures for assessing interior areas. Subsequent chapters describe relevant aspects of potential flood loss reduction measures, give an overview of special topics and issues, and outline reporting requirements. Appendixes include: references and selected examples. A glossary of terms is also provided.

CHAPTER 2

PLANNING AND DESIGN STUDY PROCESS

2-1. General.

a. Planning and design studies associated with interior areas are conducted using the same study requirements as other Corps investigations. Analysis procedures must assure that:

> "Studies shall be conducted in accordance with all applicable laws, policies, and planning guidelines. In particular the district commander shall assure that . . . the requirements and intent of NEPA* are made an integral part of the planning process" (Reference 5).

* National Environmental Policy Act

b. This chapter presents an overview of the planning and designing study process, and describes specific study considerations for interior areas. Subsequent chapters utilize this information in describing hydrologic study strategies and analytical procedures.

2-2. Study Process.

a. Feasibility studies span investigative actions from initiation of a study through formulation and evaluation of alternatives, to selection and recommendation of a plan for authorization and implementation. Design studies refine and detail the functional components and aspects of the authorized plan to better accomplish authorized purposes.

b. Feasibility studies are performed to select appropriate action to solve a water resource problem and determine if it should be recommended for congressional authorization. Objectives of feasibility studies are to formulate a broad range of alternatives and to identify and recommend the best plan to solve a water resources problem. The report specifies the project purpose, features, location and benefits; and describes the cost and scale - such as level of protection, planned mitigation actions, cost sharing, and legal and institutional arrangements to assure project functioning. Results of these investigations are documented in a feasibility report herein termed the decision document. Supporting technical studies, apart from the feasibility reports, are therefore final in terms of evaluations and impacts important to congressional decision making on a construction commitment. A reevaluation study may be required following congressional authorization. The study may be a brief reaffirmation of the survey report, if conditions have remained stable, or a reevaluation study recommending modifications to meet changed conditions. The reevaluation is essentially an updated survey report (Reference 5).

c. Advanced Engineering and Design studies consist of the General Design Memorandum (GDM) and Feature Design Memoranda (FDM). The GDM's normally are performed following approval of the survey or reevaluation study. They should primarily report on investigations concerned with the engineering design of the system components necessary to achieve the plan formulated in the feasibility study. Feature Design Memoranda are generally prepared for each major feature of large or complex project. The GDM and FDM (if needed) form the basis for preparation of plans and specifications.

2-3. Planning Study Considerations.

a. Level of Detail. The level of detail should be commensurate with the study purpose and other technical elements. The level of detail of the planning studies should be sufficient to minimize post-authorization changes (Reference 5). Analyses should identify the type, size, and configuration of the components, economics (cost-benefits); financing and cost sharing; and performance criteria of each plan in the final array of alternatives. Real estate and operational requirements of the recommended plan should also be clearly defined.

b. Analysis Conventions.

(1) Economic and other project impact analyses are performed by the Corps of Engineers and others for several time- and development- related conditions. Important conventions are existing, base, and future conditions for with and without proposed project features in place.

(2) Existing conditions for the study area consist of measures and conditions presently in place. Base condition refers to measures projected to be in place during the first year of operation of the adopted plan. Analyses are performed for with and without flood loss reduction measures in place, the difference representing the accomplishments of the project. Existing measures, implemented prior to the base year, and measures authorized and funded for construction completion prior to the base year are assumed to be in place and included for both with and without conditions as described in the Planning Guidance Notebook (Reference 14).

(3) Determination of existing without plan conditions is an important aspect of the study process. The without plan is the condition most likely to prevail in the absence of the plans under investigation by the Corps. Existing flood hazard reduction projects should be considered in place with careful consideration given to the actual remaining economic life of existing structures. Flood hazard plans authorized for implementation, but not yet constructed, should be considered in place unless it can be clearly shown that implementation of the measures is unlikely.

(4) Assessments of the existing without conditions shall be of sufficient detail to establish viable economic (cost and flood damage), social, and environmental impact assessments of with conditions without further refinements throughout the remainder of the planning process.

(5) Future condition analyses are performed for the most likely future development condition projected to occur without the project. The impacts of implementing the project future with conditions are determined by comparisons to the without condition. The assessments are performed for specified future time periods. Sensitivity analyses may also be desirable or required to determine the stability (viability and operation) of measures and plans for other possible alternative future development scenarios. The basis for projecting changes in the existing conditions must be clearly stated. Projections must be based on supportable information.

c. Formulation and Evaluation.

(1) Procedures for formulating and evaluating flood loss reduction measures of interior areas are similar to planning procedures used in other types of investigations (Reference 7). The complexity of the process is dependent upon the nature of the study area, flood hazard, damage potential, and environmental and social factors. A comprehensive array of alternatives is formulated and evaluated through an iterative process until a final array of plans is developed.

(2) The types of measures (and performance) that are formulated into alternative plans should, most often, be significantly different. Alternative plans are formulated to emphasize and address different planning objectives. The final array of plans should thus address markedly different means of accomplishing one or more of the basic planning objectives.

(3) The formulation process should develop a variety of plans including plans that maximize national economic development (NED) (Reference 8) and consider environmental issues and nonstructural opportunities. The formulation process should develop and assess a Standard Project Flood protection plan for urban areas. This plan, along with the NED plan, typically identifies upper and lower bounds of likely project features, and provides insights as to the sensitivity and functional characteristics of the system and study. Other plans, comprised of different configurations, types of components, and performance standards, should also be formulated and evaluated.

(4) The NED plan is considered an anchor point from which recommended plans can be adopted. Selecting plans other than the NED plan must be well justified (Reference 7). In areas where the potential for catastrophic losses exists, plans with the Standard Project Flood level of protection as a minimum goal must be evaluated. Where failure of the measures would not result in catastrophic loss, the NED plan is the objective. The NED plan is the recommended plan for agricultural areas.

(5) Environmental considerations are an integral part of the formulation process, and its consideration is required by the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (Reference 1). Nonstructural measures can often be valuable components of interior plans. Comprehensive planning considers nonstructural measures as realistic candidates for reducing flood losses.

d. Plan Selection. The plan selected for recommendation is expected to emerge from the several steps involved in the planning process. The attributes, costs and benefits, and other impacts (those not possible to define monetarily) of the final plans, and degree to which they accomplish the basic planning study objectives are weighed to determine the recommended plan. The evaluation and formulation should be performed with active public participation and the final plan selection accomplished in that spirit. Costs and benefits should weigh heavily in the selection, but functional performance and considerations of social and environmental impacts should also receive major consideration. The hydrologic engineer should assume a major responsibility for assuring that the selection process adequately considers functional performance.

2-4. Design Study Considerations.

a. Overview. Corps of Engineers' policies related to design studies are documented in engineering regulation, Engineering After Feasibility Studies (Reference 10). The General Design Memorandum (GDM) and Feature Design Memorandum (FDM) study the detail design of the selected plan authorized by Congress. The type of components, configuration of the system, and performance standards are specified as part of the plan. The design study provides refinement detail sufficient to meet construction and subsequent operation and maintenance criteria. Refinement decisions are based on cost effective assessments of components and other aspects while maintaining the integrity of the recommended plan. Hydrologic design analyses should interface with other design elements to meet design objectives defined above.

b. General Design Memorandum. Post-authorization studies of individual projects require the submission of a General Design Memorandum which provides an overall technical project perspective. The GDM is primarily a functional design document concerned with technical design of the system components selected in the Survey study. There may be individual feature design memoranda in certain circumstances.

c. Feature Design Memorandum. The Feature Design Memorandum, after approval, is the basis of preparation or plans and specifications of an authorized project. For complex projects, the results of the design studies of individual features of a project are prepared in separate feature design memoranda. These are scheduled so that the preparation of contract plans and specifications for individual features, which depend on prior approval of other feature design memoranda, will not be delayed.

CHAPTER 3

HYDROLOGIC STUDY STRATEGY

3-1. General. This chapter describes a general strategy for performing the hydrologic analysis associated with planning and design investigations of interior areas. Study strategy is defined as the study procedures, assumptions, and related activities commensurate with the study process described in Chapter 2. Hydrologic study procedures are presented within this framework for feasibility and design (GDM and FDM) investigations.

3-2. Minimum Facility Concepts.

a. The hydrologic study strategy is formulated on the premise that interior facilities (that will be a component of the recommended plan) will be planned and evaluated separately (incrementally) from the line-of-protection project. The major project feature (levee/floodwall) is conceptually divided from the planned interior facilities by initially evaluating a "minimum" interior facility considered integral to the line-of-protection. If a levee/floodwall is in existence, the "minimum" interior facility is that presently in place, and no special efforts are required to establish the separation. If a levee is being proposed (planned), the "minimum" facility must be formulated and the evaluation of the line-of-protection benefits performed with the facility in place. The residual interior flooding problem is the target of the interior facility planning efforts, and benefits attributable to the increased interior facilities will be the reduction in the residual damage. See Section 6-4 for a more complete discussion of the conceptual separation and determination of damage reduction benefits attributable to the levee, floodwall and additional interior facilities.

b. The "minimum" facilities are intended to be the starting point from which additional interior facilities planning will commence. The suggested criteria for determining the "minimum" facility presented is intended to yield facilities that can be quickly and easily determined. The facilities will, except in rare cases, be found inadequate upon further interior facility planning; thus increased facilities will be formulated, evaluated, and included as a component of the recommended line-of-protection plan that is an incrementally justified component of the overall flood control project. It is expected that the interior facilities included in the final plan will provide interior area flood relief for residual flooding.

c. The minimum facility should provide interior flood relief such that during low exterior stages (gravity conditions) the local storm drainage system functions essentially as it did without a levee in place for floods up to that of the storm sewer design. If a local storm drainage system is in existence, then the minimum facility should pass the local system design event with essentially no increase in interior flooding. If no local system

presently exists, but future plans include a storm drainage system, it is reasonable to proceed as if it exists and its design capacity is consistent with local design practices.

d. Minimum interior facilities will most often consist of natural detention storage and gravity outlets sized to meet the local drainage system. However, they may include other features, such as, collector drains, excavated detention storage, and pumping plants if they are more cost effective.

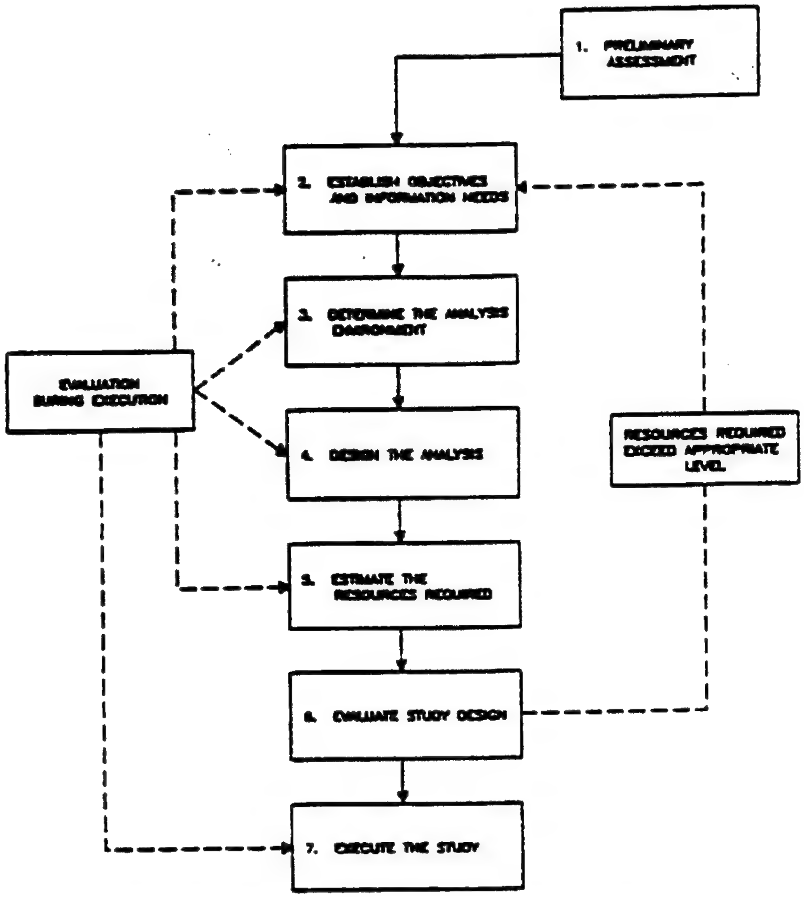
e. Special case situations may arise in which the "minimum" interior facility concept is simply not applicable. Examples may include coastal areas where a significant portion of the interior water comes from wave splash over the line-of-protection; alternatives for interior flooding that substantially reduce the volume of water arriving at the line-of-protection, such as diversions or line-of-protection re-alignment; and line-of-protection projects in which the interior facility is a significant element in the overall project or where the interior measures are integral to the project in such a manner that separation is impractical. In the above and other similar situations that may arise during an interior study, the analyst is encouraged to adhere to the concept of separable evaluation and justification as much as practically possible to ensure careful analysis of interior solutions. Where completely impractical, the reason should be documented and the analysis proceed in a logical, systematic manner considering the line-of-protection works and interior facilities as a unit.

3-3. Overview of Hydrologic Study Strategy.

a. Hydrologic analyses of interior areas must address the coincident nature of flooding at the line-of-protection for existing and future "with" and "without" conditions.

b. Development of the hydrologic engineering study strategy is an important first step in producing quality technical results needed. Figure 3.1 is a schematic of steps that can assist in formulating the hydrologic study. Table 3.1 summarizes hydrologic study detail for planning and design studies.

c. Study resources include manpower, schedules, and funding allocations for the various participants in the study. Resource allocation should be a coordinated effort among the study manager and representatives of the various elements. Under some circumstances, adjustments in scope of the hydrologic aspects of the study to meet resource allocations may be accomplished by reducing the number of alternatives investigated or by modifying the of analysis procedures. Appropriate detail and scope must be maintained, however, to meet required guidelines, regulations, and study procedures. Compromises between the study coordinator and the participant in resource allocations requirements may be required to meet these objectives.



1. Perform steps 2 through 6 in an abbreviated manner to formulate the relationship between overall interdisciplinary study objectives, strategy and the study resources required to meet these objectives.

2. Assist in formulating overall study objectives and strategy. Identify decisions required to carry out the strategy and meet the objectives. Establish information required to support these decisions. Be specific as to what, where, when, quantity and quality.

3. Assess the physical (meteorological, topographic, infrastructure, etc.) conditions influencing the study design. Determine the data that is available and its quality.

4. Develop an analysis strategy and select procedures that will provide the information required to meet the overall study objectives in a manner that effectively utilizes resources. Establish requirements for data to be acquired, sources and quality.

5. Develop a detailed work plan to carry out the analysis designed in step 4. Be specific as to who, what, where, when, how, quantity and quality. Document the analysis design, working plan and resource requirements. Tabulate resources needed to carry out each task and provide each information requirement.

6. Evaluate the analysis design, resources required, the study/design objectives, and make adjustments as considered appropriate. If the resources required (established in step 5) exceed what is considered appropriate then return to step 2 and reestablish overall study objectives; do not change the analysis without adjusting the objectives.

7. During execution periodically evaluate the objectives, analysis, and resources; make adjustments as considered appropriate.

FIGURE 3.1 Hydrologic Study Design

Table 3.1
Hydrologic Analysis Process*
Level of Detail Guidelines

Type of Study	Comments
I. Feasibility	
A. Preliminary	A. Rough hydrology, simplified procedures, judgements, and information from previous studies.
B. Formulation Process	B. Final existing and future without condition hydrology. Continuously enhanced detail for each iteration of analysis of alternatives.
C. Evaluation/Plan Selection	C. Final hydrology for plan selection, justification, and impact assessments; i.e., discharge frequency functions, performance criteria, definition of operation and maintenance procedures, and legal and institutional requirements.
II. Reformulation (when required)	Use feasibility hydrology unless conditions change. If conditions change, proceed as described above for feasibility studies.
III. General Design Memorandum (GDM)	Final design level (cost effective analysis) for pumping stations, interior channels, gravity outlets, ponding areas and other measures based on the component sizes, configuration, and performance criteria established in Part II. Provide detailed O&M, legal, and institutional requirements.
IV. Feature Design Memorandum (FDM)	Refinements to GDM design for major plan features, such as pump stations. Refine operation of plan, etc.
V. Operations Manual	Describe in detailed operations manual hardware (streamgages, raingages, etc., necessary to operate the selected plan).

*Process is ideally conceived to proceed from I to V as shown.

3-4. Strategies for Planning Studies.

a. Hydrologic Study Strategies. Hydrologic study strategies presented for planning studies are procedures and actions directly applicable to the Corps planning process.

b. Existing Without Condition System Layout. Existing without conditions system layouts are based on criteria and requirements defined in paragraph 2-3c. Specific criteria and considerations in laying out the study area are:

(1) The system is assumed to be in place and operating as planned, if the line-of-protection (levee, floodwall, seawall) is presently in place or authorized for construction.

(2) If the line-of-protection is not presently in place, its feasibility and specification will be determined based on appropriate formulation and evaluation procedures. The feasibility study will include plans of alignment of the line-of-protection which minimize the contributing runoff area to the interior. This requires special attention to tie back levees, diversions, and use of pressure conduits (Reference 4).

(3) If, as in the above paragraph 3-4b(2), the line-of-protection is not in place, a minimum facility (described in paragraph 3-1) will be formulated and considered as part of the line-of-protection system.

c. Existing Without Condition Assessments. Hydrologic analyses of existing without conditions will be performed to develop the basis for which the interior facilities will be planned. The analyses provide flood hazard information (frequency, magnitude, elevations, velocities) which are integrated into assessments of other study elements (i.e., flood damage, cost, social and environmental). Hydrologic analyses include development of data for estimating elevation-frequency functions (discharge or storage based) at desire locations throughout the system. The general hydrologic strategy for analyzing existing without conditions is:

(1) Assess available information.

(2) Perform field reconnaissance of the area: conduct interviews, survey data needs, gather historic event information, determine physical and operational characteristics of existing components.

(3) Assess analytical criteria for performing the study; i.e., layout for line-of-protection and existing condition components; determine subbasin and damage reach delineation and existing land use patterns.

(4) Analyze exterior stage conditions at existing or potential outlets of interior facilities.

(5) Develop rainfall-runoff analysis parameters for the interior areas as appropriate. Parameters include data for rainfall, loss rates, runoff transforms (unit hydrograph, or kinematic wave), and routing criteria. See EM 1110-2-1408 (Reference 3), EM 1110-2-1405 (Reference 2), and HEC Training Document No.15 (Reference 12).

(6) Formulate and evaluate the minimum interior facility described in paragraph 3-1b.

(7) Generate hydrographs for the interior system by rainfall-runoff analyses, combine flows, and perform channel and storage routings as required throughout the system. The coincident flood routings (interior and exterior stage considerations) through the line-of-protection at existing gravity or pressure outlet and pumping station location may be performed separately or in conjunction with the other system analysis. Seepage contributions should be included if pertinent.

(8) Develop elevation (discharge or storage based) frequency functions or event parameters (historic record analysis) at selected damage reaches and other locations.

d. Future Condition Assessments. Future without analyses repeat the hydrologic strategy and procedures defined under existing without conditions for the most likely future conditions as defined in paragraph 2-3c(2). This includes both land use and conveyance system changes. Other future alternative land use conditions may be assessed if desired or necessary. Future land use development patterns and other actions may affect hydrologic loss rates, runoff transforms and possibly natural storage and conveyance areas. These effects, including assumptions of encroachment, sediment, and maintenance requirements to maintain the functional integrity of the proposed project, must be determined and documented. Analyses of future with and without project conditions are normally developed and presented at decade intervals throughout the life of the proposed project (Reference 8).

e. Formulation and Evaluation. Hydrologic analyses of flood loss reduction actions and measures are performed for several combinations of measures (plans), operation plans, and performance targets following the broad approach outlined in Chapter 2. The initial evaluation should assess the potential for improved operation of the existing system. If improved operation procedures are found to be attractive for the present system they should be detailed and incorporated as part of the existing system. The typical sequence of the feasibility analysis is to evaluate increased gravity outlet capacity initially, ponding second, pumping stations third, interceptor systems fourth, and then other measures. A description of these measures is presented in detail in Chapter 5.

f. Other Study Considerations. There are several important subproblems that must be resolved by the hydrologic engineer in the formulation and evaluation of proposed interior systems. Among these are such items as

exterior elevations for gravity outlet gate closure and pump on and off elevations. If they can be determined by independent analysis involving only of hydrologic factors and the results do not significantly affect plans that are formulated and evaluated, then the hydrologic engineer should solve them. If they interact in important ways with the measures being formulated, these technical subproblems should be incorporated into the planning process that considers costs, benefits, and impacts of measures. It is often useful to examine the sensitivity of the performance of the planned interior facilities to variations in such factors.

(1) The basic concept as discussed briefly in paragraph 2-3f is that the recommended plan will emerge from the planning process considering the full range of concerns and planning objectives. Costs and benefits will dominate, but other social, environmental, and functional performance issues are important.

(2) The performance of the interior facilities over the full range of anticipated interior events, including those that exceed the design level, are particularly important. What happens when design is exceeded? Do excess waters rise slowly or rapidly? What is the warning time for evacuation? Can interior area occupants get into and out of the area as needed? What are the provisions for emergency services (police, fire protection, medical service) and other life support requirements (food, water, shelter, and power)? Will the formulated facilities continue to function as planned under conditions that may prevail during the occurrence of a full range of possible interior storm events up to the magnitude of the Standard Project Storm. The hydrologic engineer should participate in the decision process in these and similar items for which his technical expertise is particularly helpful.

3-5. Strategies for Design Studies.

a. The General Design Memorandum (GDM) and Feature Design Memorandum (FDM) studies detail the selected plan specified at the conclusion of the planning process. The type of components, configuration of the system, and performance standards are specified as part of the plan. The design study objective is to provide refinement detail sufficient to meet construction and subsequent operation and maintenance criteria. Another major objective is to perform cost effective assessments of the refinements and components while maintaining the integrity of the recommended plan. Hydrologic design analyses should interface with other design elements to achieve those objectives. This should include hydraulic design elements of the recommended plan such as the size, invert elevations, and development of rating curves for gravity outlets, pumping station sump dimensions, and water surface profiles and flow velocities associated with proposed runoff conveyance system (Reference 2).

b. Selected hydrologic design considerations are described below. The items vary with each study.

(1) Pump station requirements include: Pump start and stop elevations; selection of desired pump floor elevation and determination of the need for

flood proofing above the floor elevation; the extent of automation of the pump station operations to be commensurate with the extent of advance warning time.

(2) River data and criteria commensurate with gravity outlet capabilities including selection of final gravity outlet gate closure elevations and the need for a manual or automated system of opening gravity outlets when interior pond stages exceed river stages.

(3) Detention storage requirements include: storage allocation for sediment, final interior stage frequency curves, duration and depth data to determine potential hazards associated with ponding, and the real estate requirements (permanent right-of-way and/or flowage easements).

(4) Other hydrologic evaluations include: final assessment of impacts from interior runoff events which produce interior stages exceeding selected pond right-of-way, pump station floor elevations, and other existing development elevations, including the impacts from the standard project storm; and the determination of cofferdam levels for the construction of the interior flood control features (may include the development of seasonal stage frequency curves for anticipated construction schedules). Seepage can be a major consideration where external river stages remain high for prolonged periods.

(5) The actions required to operate and maintain the proposed system must be described in detail. These include flood warning-emergency preparedness components and actions. The operations and maintenance requirements should be described by flood stage or elevation.

CHAPTER 4

HYDROLOGIC ANALYSIS PROCEDURES

4-1. General.

Four hydrologic analysis procedures (and variations) are discussed herein and are classified as: (1) continuous record analysis methods, or (2) coincident frequency methods.

4-2. Basic Concepts.

a. The occurrence of fluctuating water levels both exterior and interior to the line-of-protection is the aspect that makes interior area analysis unique. Several terms are used to communicate information about the nature of these occurrences and they represent important basic concepts. If the exterior and interior occurrences are such that a consistent relationship exists one to the other (to some degree, one can be predicted from the other), the interior and exterior events are said to be correlated. If the physical and meteorologic processes of the interior and exterior events are related to one another, they are said to be dependent. If the situation occurs that the interior and exterior events produce stages that coincide, e.g., the exterior is high when an interior event occurs, then coincidence is said to occur. Coincidence can exist whether or not the interior and exterior occurrences are correlated or dependent.

b. At one extreme it is possible, though not likely, that there will be complete non-coincidence, i.e., the two occurrences will never coincide and thus interior and exterior water levels will never be high or low at the same time. The interior analysis could be performed without consideration of exterior conditions, thus greatly simplifying the problem. The occurrences could be correlated and dependent/or independent, but it would not be important to the analysis approach.

c. At the other extreme, it is possible, and somewhat more likely, that there will be complete coincidence, e.g., the two occurrences will always coincide so that high exterior levels are always present in the case of the occurrence of an interior event. The interior analysis can proceed without exterior analysis (by assuming blocked gravity outlets), since the conditions that exist for interior events are completely known. The occurrences would likely be correlated, although not necessarily dependent, but it would not be important to the analysis approach.

d. The situation for a given study will most likely lie between these two extremes. Analysis to determine the degree of correlation may help determine the likelihood of coincidence or independence but are not sufficient of themselves. Correlation studies are most useful for developing (if needed) a predictive capability. Formal study to determine the degree of independence is not possible at the present time, as it represents an unsolved technical problem area. To some degree, lack of correlation can

suggest independence but is not sufficient of itself. More likely, the degree of dependence is determined based on inspection of the available record and judgements with regard to the meteorologic and physiographic origins of the interior and exterior events. It is important that the context be carefully defined; the fact that storms occur only in the winter (spring, etc.) is not an adequate basis for declaring that the occurrences are dependent. The critical focus must be on the aspects of the occurrences as they relate to possible coincidence, since this is the critical item with respect to analysis. The validity of the assumptions necessary for application of the coincident frequency method is controlled by whether or not independence is the case.

e. Inspection of the historic record is fundamental to determining important factors of correlation, independence, and coincidence. Establishing bounds on the consequences of decisions regarding these factors is an important analytic approach. It is generally helpful to analyze the two extremes of assuming complete and non-existent coincidence. Also, by determining the relative consequences of the assumption of independence, judgements regarding its importance to the study can be made. Within the framework of this information, the approach that will yield supportable conclusions will become more evident. Table 4.1 summarizes hydrologic analysis considerations for various levels of coincidence and dependency of interior and exterior conditions.

Table 4.1

Assessment of Coincidence
(Reference Paragraph 4-02)

COINCIDENCE	DEPENDENCE	EXAMPLES/COMMENTS	ANALYSIS CONSIDERATIONS
(HIGH)	(HIGH)	Hurricanes, large regional events; interior and exterior areas of similar magnitude.	Blocked gravity outlet conditions are common. Conventional hypothetical frequency analyses often appropriate for urban areas.
	(LOW)	Storm season of small interior area season coincides with snowmelt runoff of large basin.	Continuous record analysis methods or probabilistic approaches generally required. Gravity outlet is often blocked during critical interior events.
	(HIGH) (LOW)	This range of coincidence is most common. Relatively high likelihood of interior and exterior events occurring simultaneously.	Continuous record analysis or probabilistic methods generally required. Gravity outlets may be blocked during critical interior events.
	(HIGH)	Timing of interior and exterior events is such that they rarely coincide. May be affected by operation of upstream project.	Considerable study may be required to identify this condition and to assume its existence in the physical process. Coincident hydrology generally appropriate.
(LOW)	(LOW)	Rare condition. Interior flooding rarely if ever coincides with high exterior stages. Studies generally limited to gravity outlet assessments.	Coincident interior analysis is not necessary.

4-3 Procedure Overview.

a. General. Two basic hydrologic procedures for analyzing with and without interior project conditions are presented. These approaches are continuous record analysis methods, and coincident frequency methods.

b. Continuous Record Analysis Methods. Continuous record procedures can be subcategorized as:

(1) period-of-record (historic),

(2) discrete events of historic record, and

(3) stochastically generated continuous records.

Analysis of multiple discrete events are included as a continuous analysis method since events relating to coincident flooding of local runoff and river stages are identified from historic record of river stages, interior stages, and rainfall. Each of the three techniques may be used to develop hydrologic data of coincident flooding adjacent to the line-of-protection. Paragraphs 4-5, 4-6, and 4-7 describe the basic elements of the procedures.

c. Coincident Frequency Methods. Coincident frequency methods vary significantly in detail and procedures. The technique described herein develops a weighted frequency relationship from probabilities of exterior and coincident interior stage conditions. Section 4-8 describes the procedure in detail.

4-4. Hydrologic Data Requirements.

a. General. Hydrologic data required for analysis of interior areas include: topography, exterior stage data, historic rainfall records, runoff parameters, and seepage data. Physical characteristics and operation procedures for the without condition must also be determined.

b. Topography. Topographic data are required to define watershed and subbasin boundaries, runoff parameters (slopes, stream lengths), and estimation of elevation-area-storage relationships for natural detention areas. The availability of good topographic data as early in the study as possible is recommended.

c. Exterior Stage Data. Exterior stage data are required primarily at gravity and pumping station outlet locations. Secondary gravity outlet data may be aggregated (combined rating curves) to primary outlet locations, or ignored if the discharge capacity is insignificant relative to the primary outlets.

d. Rainfall Data. Rainfall data are required for interior and possibly for exterior areas analyses. The data should be basin average values for the study area, with weighted rainfall values determined where more than one rain

gage is located within or near the watershed. If no rainfall gage exists in the basin, records from nearby rain gages will be used in the analysis.

e. Runoff Parameters. Hydrologic parameters affecting runoff are required for loss rates, runoff transforms, and base flow. Loss rate parameters may be initially estimated by using values from previous studies, or derived through analysis of measured rainfall and runoff volumes at gages. Loss rates are generally based on the land use antecedent soil moisture condition, and physical basin characteristics. Initial values for unit hydrograph and other runoff transform parameters may be estimated from land use and physical basin characteristics using published values or regression equations. The importance of volume rather than peak discharge in many studies permit use of simplified runoff methods to be employed with acceptable results. Calibration studies of assumptions, and verification of results to high water marks and frequency information must be performed as needed.

f. Physical and Operational Characteristics of Existing Measures. Information on physical and operational characteristics of existing flood loss reduction measures are normally required. Gravity outlet locations, capacity , and operation procedures are needed to enable simulation analysis to reproduce the historic record.

g. Other Data. Data on ponding areas, collection systems, and any hydraulic control effecting water movement are also often necessary.

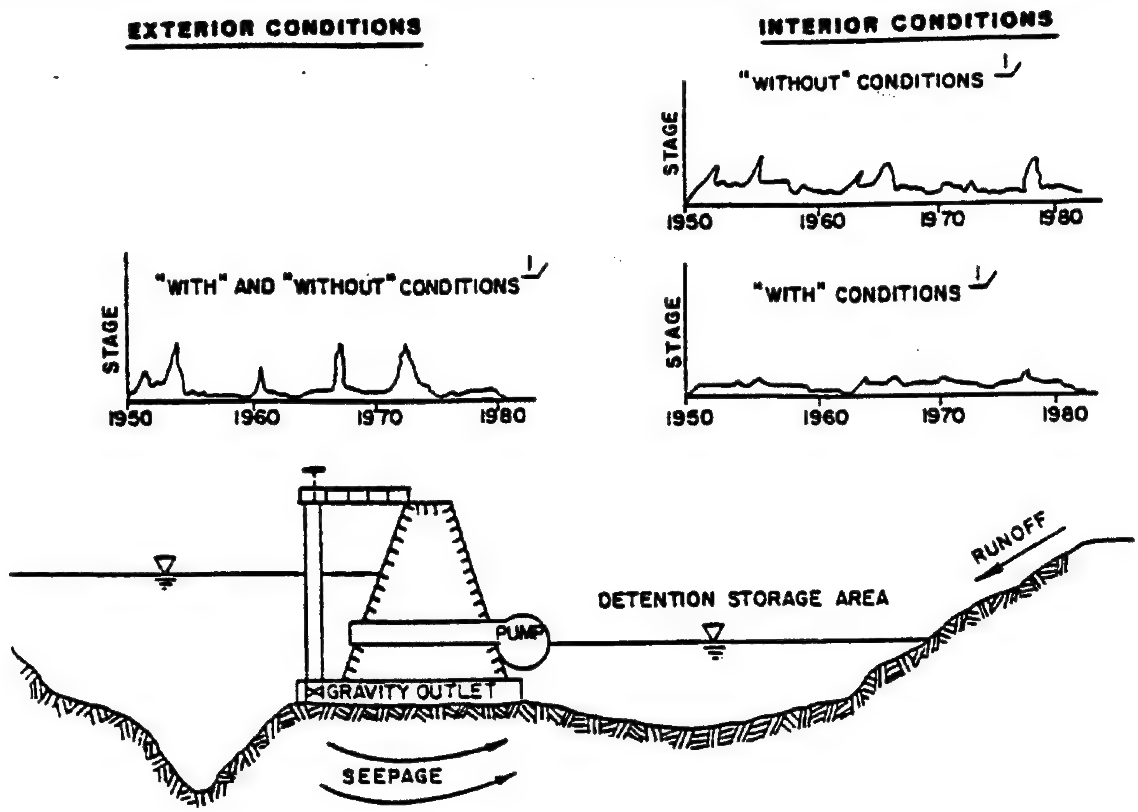
4-5. Period-of-Record Methods.

a. General. Period-of-record methods involve analysis of continuous historic records of hydrologic events. Analyses are performed for with and without conditions. The procedure consists of performing sequential hydrologic simulation of inflow, outflow, and change in storage to derive interior water surface elevations given exterior stages and interior runoff for the entire period-of-record.

b. Overview.

(1) An overview of the period-of-record methodology is depicted in Figure 4.1. Historic precipitation data typically are applied to subbasin loss rate, runoff transforms, and base flow parameters to yield runoff hydrographs at subbasin outlets. Hydrographs are combined and routed through the system (as appropriate) to gravity outlets and pumping stations to yield period-of-record inflows at the line-of-protection. These data are used with period-of-record exterior stage data to simulate the expected operation of the system. The results are period-of-record stage hydrographs at desired locations throughout the interior system. For urban areas, elevation-frequency functions are often derived for economic analyses. In agricultural crop areas, the stage hydrographs (stages and duration by season) are typically used to calculate crop damage directly.

(2) The period-of-record procedure is attractive because it preserves the seasonality, persistence, and dependence or independence of



1/ WITHOUT AND WITH CONDITIONS TIME TRACES OF STAGE ARE DEVELOPED FOR BASE, EXISTING, AND FUTURE CONDITIONS AS APPROPRIATE FOR INVESTIGATION.

FIGURE 4.1 Continuous Record Simulation: Period-of-Record Concepts

exterior (river) stages and interior flooding. The method enables the performance of the project to be displayed in a manner easily understood by the other study participants and the public. The procedure is particularly useful for evaluating crop damage of single subbasin watersheds (ponding adjacent to line-of-protection) in agricultural areas. System operational and maintenance costs may be calculated directly. The methods are generally tedious to apply because of the large amount of hydrologic data analyzed.

(3) Major considerations in application of the period-of-record procedures are the potential for the historic record being unrepresentative (records are usually short), and that the procedure requires significant information needs and extensive calibration. A short and unrepresentative historic record may yield inappropriate size and mix of measures and operation specifications of the system. The extensive data needs and model calibration requirements often result in a period-of-record analysis that is an unduly

simplistic rainfall-runoff analysis for single subbasins adjacent to the line-of protection. The level of detail is often adequate for agricultural areas, but may not be for the runoff-routing analyses required of complex urban areas.

(4) A variation of the period-of-record method is to analyze only those events from the historic record that are relevant to the interior analysis, thus reducing the number of specific events to be evaluated.

c. Hydrologic Analysis Procedures. The sequence of analytical procedures varys with individual studies and variations in period-of-record analysis methods. Figure 4.2 illustrates period-of-record concepts. A typical study sequence is provided below.

(1) Watershed and subbasin boundaries are delineated and damage reach index locations selected where hydrologic data are developed for flood damage analysis.

(2) Interior runoff for the period-of-record is developed using historic rainfall and adopted loss rates and runoff transforms by subbasins, and then combined and routed throughout the system.

(3) Other contributing interior flows such as seepage, wave overtopping, and overflow from adjacent areas are determined for use in the analysis.

(4) Interior inflow is routed through the system including the gravity outlets, pumping stations, and detention basins, adjacent to line-of-protection.

(5) The analysis model is calibrated based on initial results. Calibration may include: generation of period-of-record flows, volumes, and stages at gages; and calibration to historic high water marks, damage data, and frequency of overtopping roads and bridges. Adjustments may be made to loss rate and runoff transform parameters, seepage functions, antecedent moisture accounting techniques, and operation procedural assumptions.

(6) Develop elevation-frequency relationships, duration of flooding, and other pertinent hydrologic information at locations of interest for the existing without conditions.

(7) Repeat steps 2, 3, 4, and 6 for future without conditions and future with conditions for each to the proposed alternative plans.

4-6. Multiple Discrete Event Method.

a. The multiple discrete event procedure is based on development of interior stage-frequency functions for areas affected by coincident flooding. The procedure generates a composite stage-frequency function from analysis of two conditions. The first involves analysis of selected (high stage) exterior events of historic record that have an effect on interior flooding when interior rainfall occurs coincidently. The second condition involves analyses

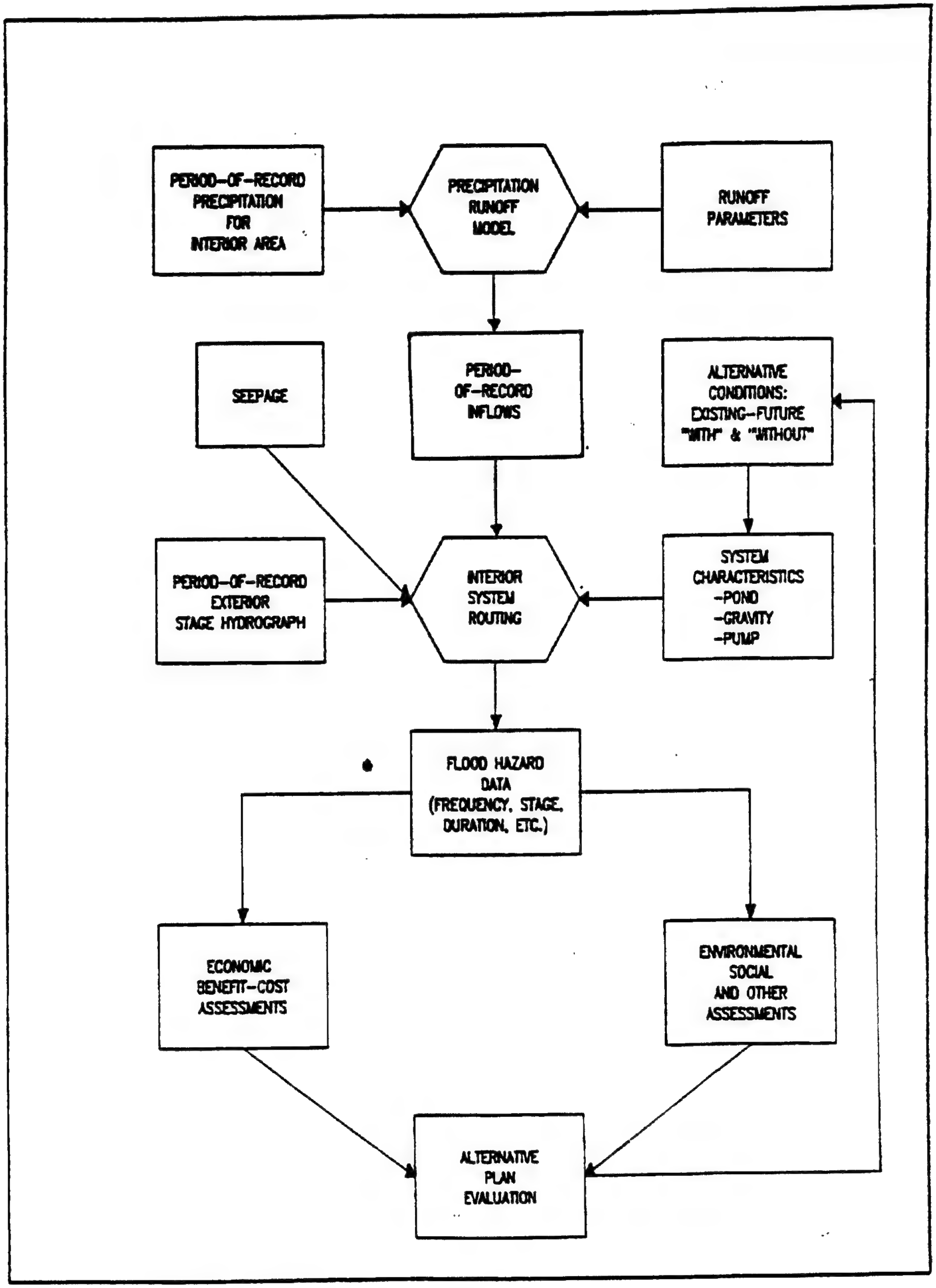
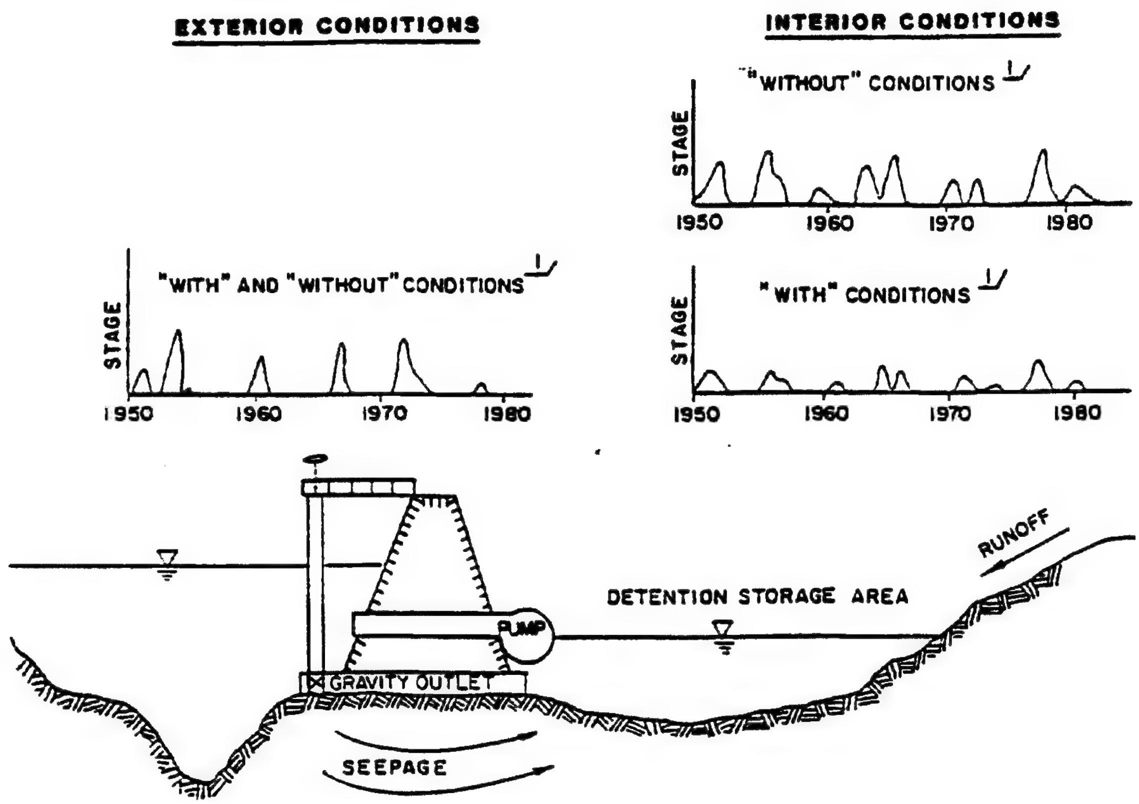


FIGURE 4.2 Period-of-Record Analysis Schematic

of low exterior stages associated with interior flood analysis generated by either coincident historic rainfall or hypothetical frequency storm events. For the second condition, historic rainfall is commonly used in agricultural areas and hypothetical frequency rainfall for analysis of urban areas. The result is a stage-frequency function for each of the two conditions. They are then combined into a composite function by the application of the joint probability theorem. Figure 4.3 conceptualizes the analysis process.



[1] WITHOUT AND WITH CONDITIONS TIME TRACES OF STAGE (BASED ON SIGNIFICANT EVENTS) ARE DEVELOPED FOR BASE, EXISTING, AND FUTURE CONDITIONS. HYPOTHETICAL FREQUENCY ANALYSIS OF INTERIOR (NOT ILLUSTRATED) MAY BE PERFORMED FOR LOW EXTERIOR STAGES.

FIGURE 4.3 Continuous Record Simulation: Discrete Events

b. The multiple discrete event method is similar to the period-of-record procedure in that the concepts of coincident flood simulation are easy to understand and antecedent moisture conditions are accountable. Both methods may be influenced by short and unrepresentative historic records. The two procedures are different in that the discrete event analysis evaluates fewer events, uses fewer parameters, and generally is more applicable for complex hydrologic systems. Combining probability functions is a distinct departure as well. The discrete event method may miss events that impact on the results, and does result in a less automated process of analysis than the period-of-record.

c. Hydrologic Analysis Procedures.

(1). The hydrologic procedures typically applied to perform multiple discrete analyses of interior areas are shown in Figure 4.4.

(2) The historic record of exterior stages is reviewed to determine the events which may have an impact on interior flooding. Dividing the record by season may be an important consideration. Unless seepage or overflow from adjacent areas or wave overtopping are significant problems, events must occur coincidently with interior events that result in damage when the gravity outlets are closed. The event definition should identify dates, be of sufficient length to determine duration and seasonal effects on the damage potential, and assess antecedent moisture conditions.

(3) Rainfall-runoff and interior routing procedures for blocked gravity outlet conditions are similar to those described for period-of-record, except evaluations are performed for single historic events. Historic rainfall data must be coincident with the exterior events selected for the analysis. Rainfall excess is applied to runoff transforms and routed to produce hydrographs throughout the interior system. Seepage and other inflow functions are developed. Total hydrographs are subsequently routed through existing gravity outlets and pumping stations. The gravity outlets are blocked until a positive differential head exists between the interior and exterior.

(4) Stage-frequency functions are developed for gravity conditions (see paragraph 1-2). The events are normally ranked in decreasing order and plotting positions established based on the historic record or hypothetical events as appropriate. The order assignments of the individual events may change with location in the system and adjustments to hydrographs resulting from physical works.

(5) Analysis of gravity conditions normally use hypothetical frequency storm and runoff analyses for urban areas and historic events for agricultural crop damage assessments. If historic events are used, maximum intensity rainfall is selected from continuous records for the period coincident with low exterior stage or unblocked gravity outlet conditions.

(6) Rainfall-runoff analyses are performed for the events and stage-frequency functions developed for desired locations. Events are routed through the line-of-protection assuming low exterior stage conditions.

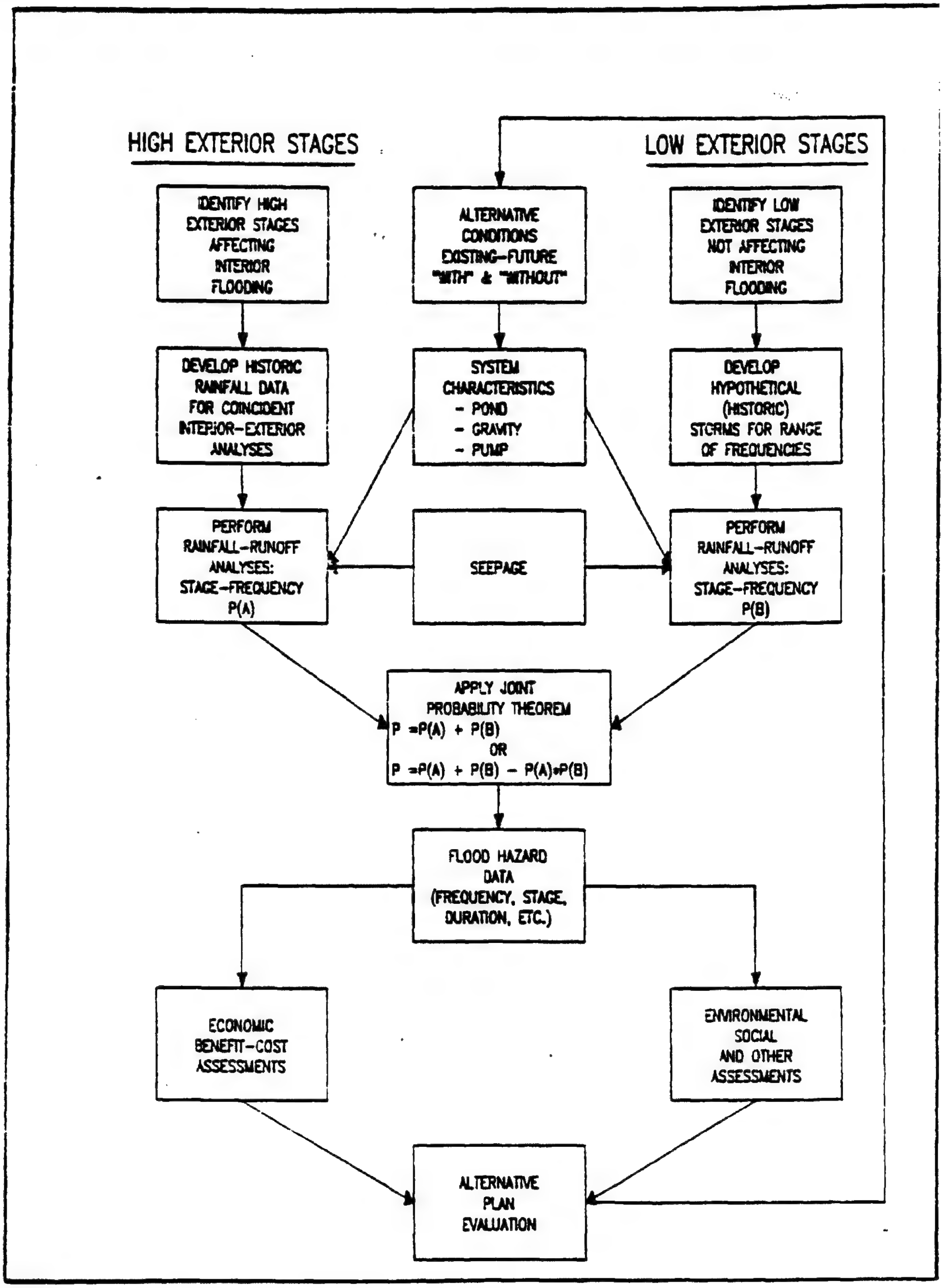


FIGURE 4.4 Discrete Event Analysis Schematic

Elevation-frequency relationships are developed at desired locations. If hypothetical frequency storms are used, the frequency functions are developed directly from the recurrence functions. For historic storms, the events are ranked and plotting positions assigned.

(7) The joint probability theorem is used to combine the frequency functions for blocked and unblocked gravity outlet conditions. For annual series, for a given stage (or flow) total probability is equal to the sum of the probability at that stage (or flow) for each relationship minus the product of their individual probabilities (to subtract probability of events occuring in the same year). For partial series (with multiple events in a year assumed to cause damage) the total probability is the sum of the two (blocked and unblocked) probability relationships.

4-7. Stochastic Simulation Procedure.

a. Conceptually, the technique of stochastic hydrology provides the means for overcoming the limitations of analysis of historical events. Stochastic hydrology techniques can provide sequences of statistically-likely hydrologic events, including combinations of interior and exterior events that may be rarer than any yet observed. If a number of such sequences can be used for the required analyses, the operation policies or design should be more resilient than those biased towards control of a specific design event. Even when a specific design event or historical sequence is employed, analysis of system response to the synthetic sequences can demonstrate the sensitivity of design or operation policies to the flow sequence.

b. Practical, tested stochastic hydrology procedures have not been widely used for analyses required for interior flood control studies. A number of synthetic streamflow generation models are in use that generate sequences of monthly, seasonal, or annual flows. However, the primary need for interior drainage studies is for sequences of daily or hourly flows. Operational models that generate such sequences are not now readily available. Generation of synthetic precipitation events analyzed with a rainfall-runoff model to develop the required sequences is an alternative approach; and, operational tools to accomplish this have been tested in an experimental mode. Ongoing research may ultimately provide practical stochastic simulation methods. Analysts should be alert to opportunities to apply such technology as it becomes more accepted and applicable for continuous record type of analyses. Figure 4.5 presents a conceptualization of applications of stochastic simulation procedures.

4-8. Coincident Frequency Methods.

a. Overview. Coincident frequency is one of several probabilistic methods that can be used to perform interior area analysis. Coincident frequency methods for performing hydrologic analyses of interior areas normally apply the total probability theorem to generate stage-frequency functions for interior areas affected by coincident interior and exterior flooding. The procedure is directly applicable to areas where occurrence of the exterior and interior events are independent. These areas often include

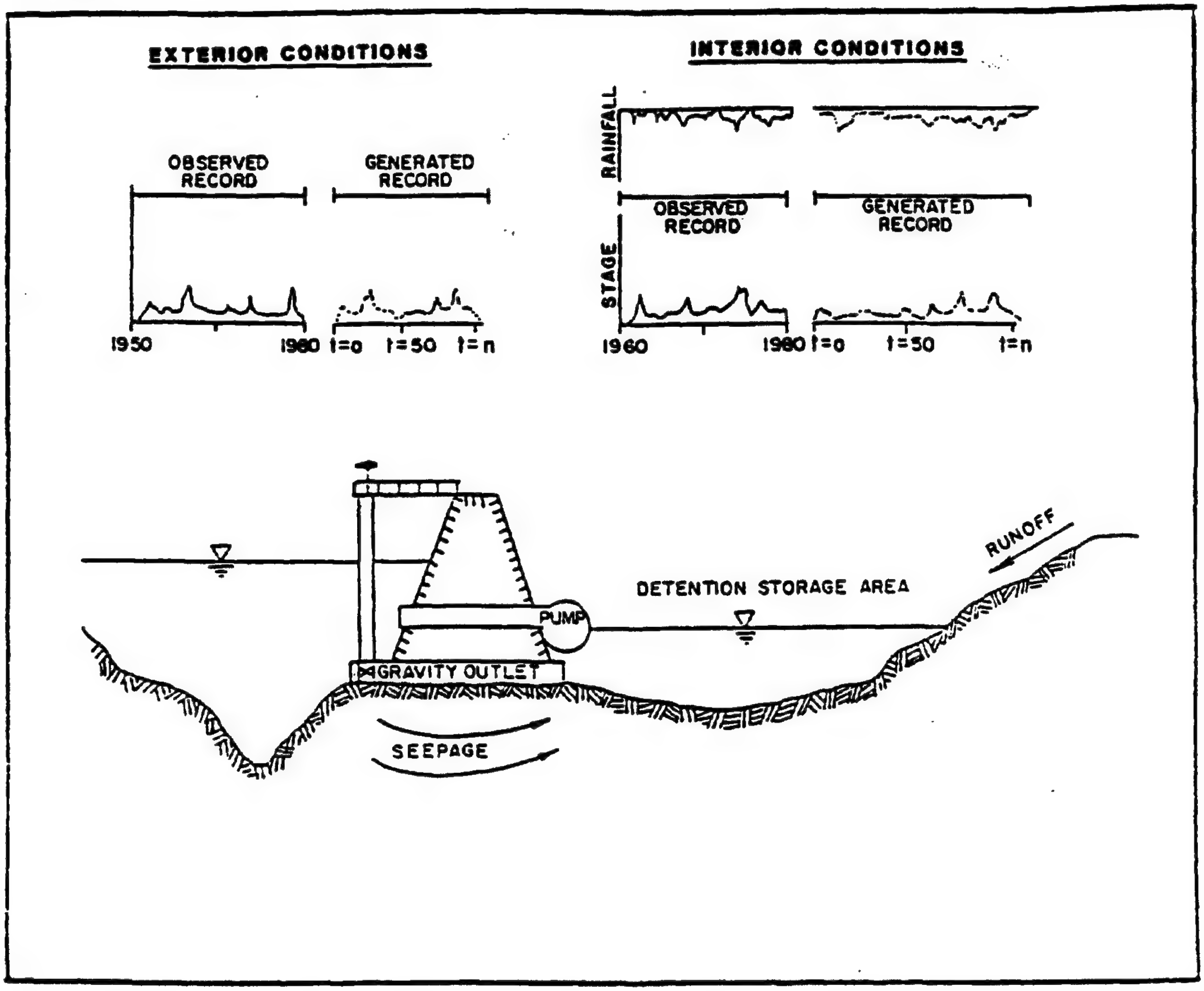


FIGURE 4.5 Continuous Record Simulation: Stochastic Concepts

relatively small interior areas located along large rivers, lakes, or coast lines. Variations in the procedures presented may be used to perform similar assessments of dependent interior and exterior event occurrences based on particular study conditions and data availability. Figure 4.6 depicts the general concepts.

b. Computation Method.

(1) The coincident frequency approach utilizes a series of hypothetical single event hydrographs for the interior analysis and stage-duration (stage versus percent of time exceeded) for exterior stages. The methods are applied for detention storage levels adjacent to the line-of-protection. Basic steps in the approach are defined below and depicted in Figure 4.7.

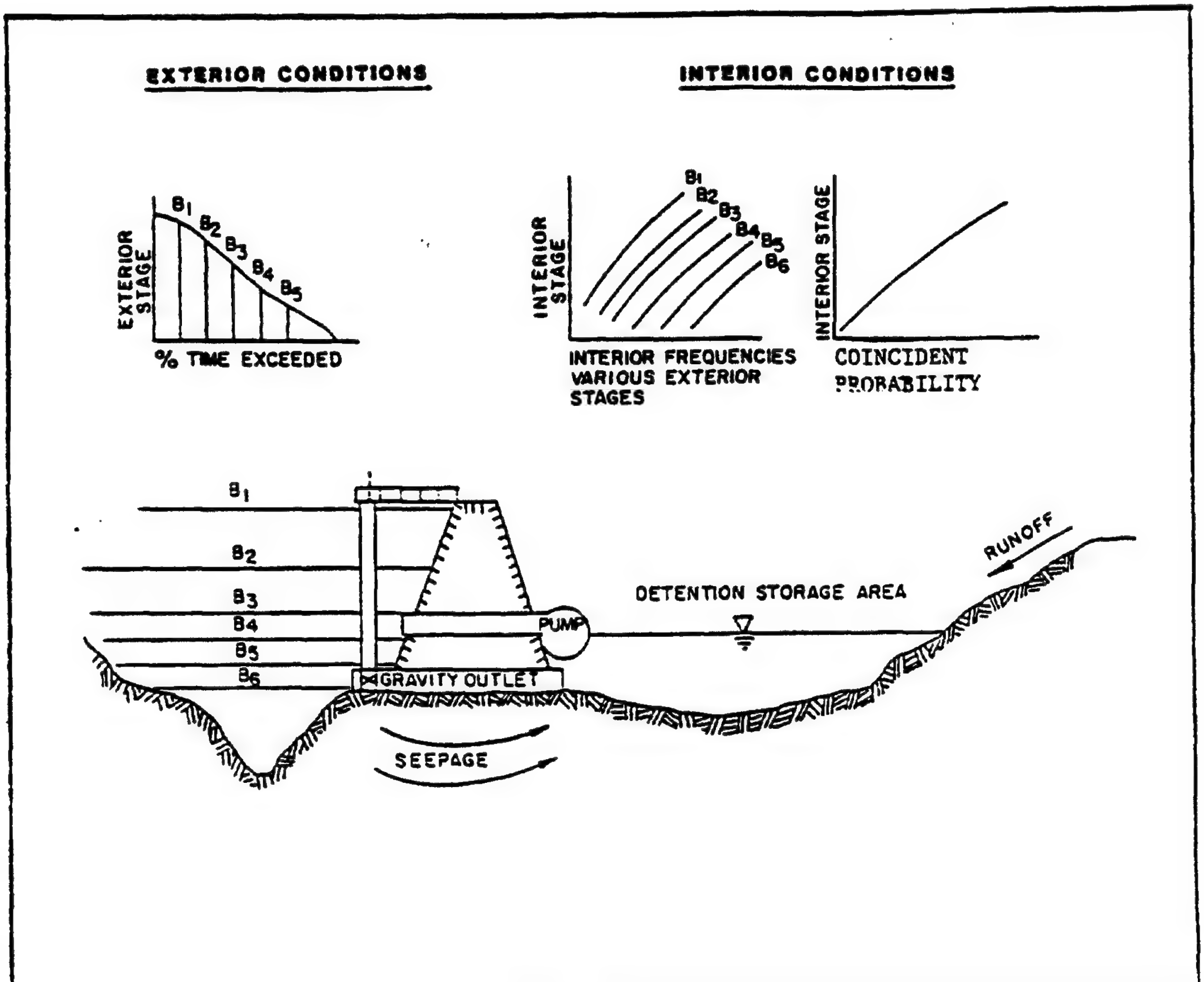


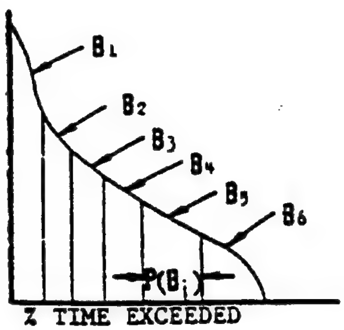
FIGURE 4.6 Coincident Frequency Concepts

Step 1. A stage-duration function is developed for exterior stages and divided into appropriate segments. The middle value of each segment is takenas an index river stage. The segment interval, $P(B_1)$, for the duration represents the probability of the interval. The sum of the probabilities must equal 1, i.e., $\sum P(B_i) = 1$.

Step 2. A series of hypothetical frequency events are analyzed for each of the exterior tailwater conditions. A stage-frequency ($P(A/B_i)$ function is developed for each exterior tailwater condition.

Step 3. The coincident detention elevation (at the outlet) vs. exceedence probability functions are developed from the conditional probability curves using the total probability theorem, where:

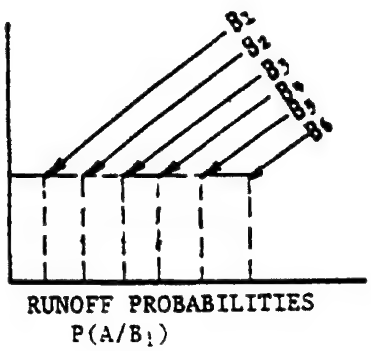
STEP 1



Develop duration (% time exceeded) functions for exterior conditions, where:

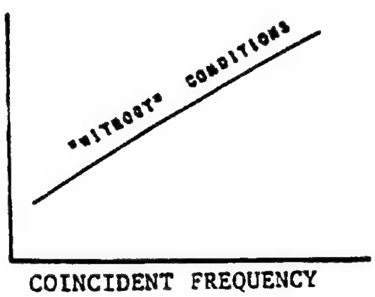
$$\sum_{i=1}^{n} P(B_i)=1$$

STEP 2



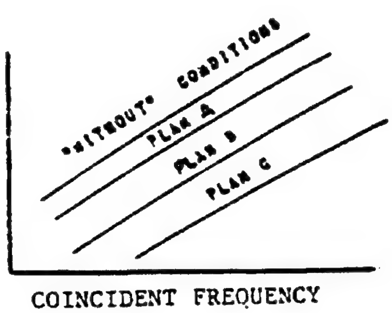
Analyze range of hypothetical interior runoff events for various frequencies and stage levels.

STEP 3



Develop weighted (coincident) probability functions for "without" condition.

STEP 4



Redo steps 2 and 3 for each alternative affecting stage - frequency relationships of interior areas adjacent to line-of-protection

FIGURE 4.7 Coincident Frequency Procedures

$$P(A) = \sum_{i=1}^{n} (P(A/Bi) \times P(B_i))$$

where: $P(A)$ = probability of exceeding a given interior ponding elevation
$P(B_i)$ = probability river is at the specific stage interval (i), where i assumes full range of values which have affect on pond elevation.
$P(A/B_i)$ = probability of exceeding a given pond elevation if the river stage is at the stage interval described in step 1.

Step 4. Steps 2 and 3 are repeated for each alternative of gravity outlet and pumping stations analyzed.

(2) The coincident frequency methods typically require less data than continuous record techniques. In general, the procedure is easier to apply and calibrate for urban interior analyses than methods involving continuous record simulation. Use of hypothetical frequency hydrographs (peak, volume, and all durations are statistically consistent with the percent chance exceedance assignment of the event) reduces the chance for nonrepresentative results that might occur from procedures using historic records. Seasonal analyses aspects for agricultural or other such analyses may be performed by generating and weighting the information by seasons and weighting appropriately to obtain annual values. However, in practice, these procedures have not been fully developed and are less direct than from continuous record simulation methods.

(3) The coincident frequency concepts for analyzing interior areas are more difficult to explain (in lay terms) and understand than period-of-record concepts. The assumption of independence of events may not be valid. Also, the method does not provide direct means for estimating operational costs and impacts of damage resulting from timing and duration of flooding that, for example, might be important in evaluating agricultural crop damage.

c. Analysis Procedures.

(1) Overview. The analytical procedures using the coincident frequency methods vary with individual studies. Figure 4.8 illustrates the general analysis process.

(2) Delineation of Area. Delineate watershed subbasin boundaries and establish damage reach index locations where hydrologic data (discharge or elevation-frequency functions) are required.

(3) Exterior Stage Data. Develop stage-duration (percent of time stage is exceeded) relationships at primary outlet locations. The relationships are typically developed using historic gaged data. The data are often transferred from a nearby gage. Adjustments may be needed if exterior stage differences between the gage location and study location are significant.

(4) Rainfall-Runoff Analysis. Rainfall-runoff analysis of the interior area is performed to generate stage-frequency relationships at

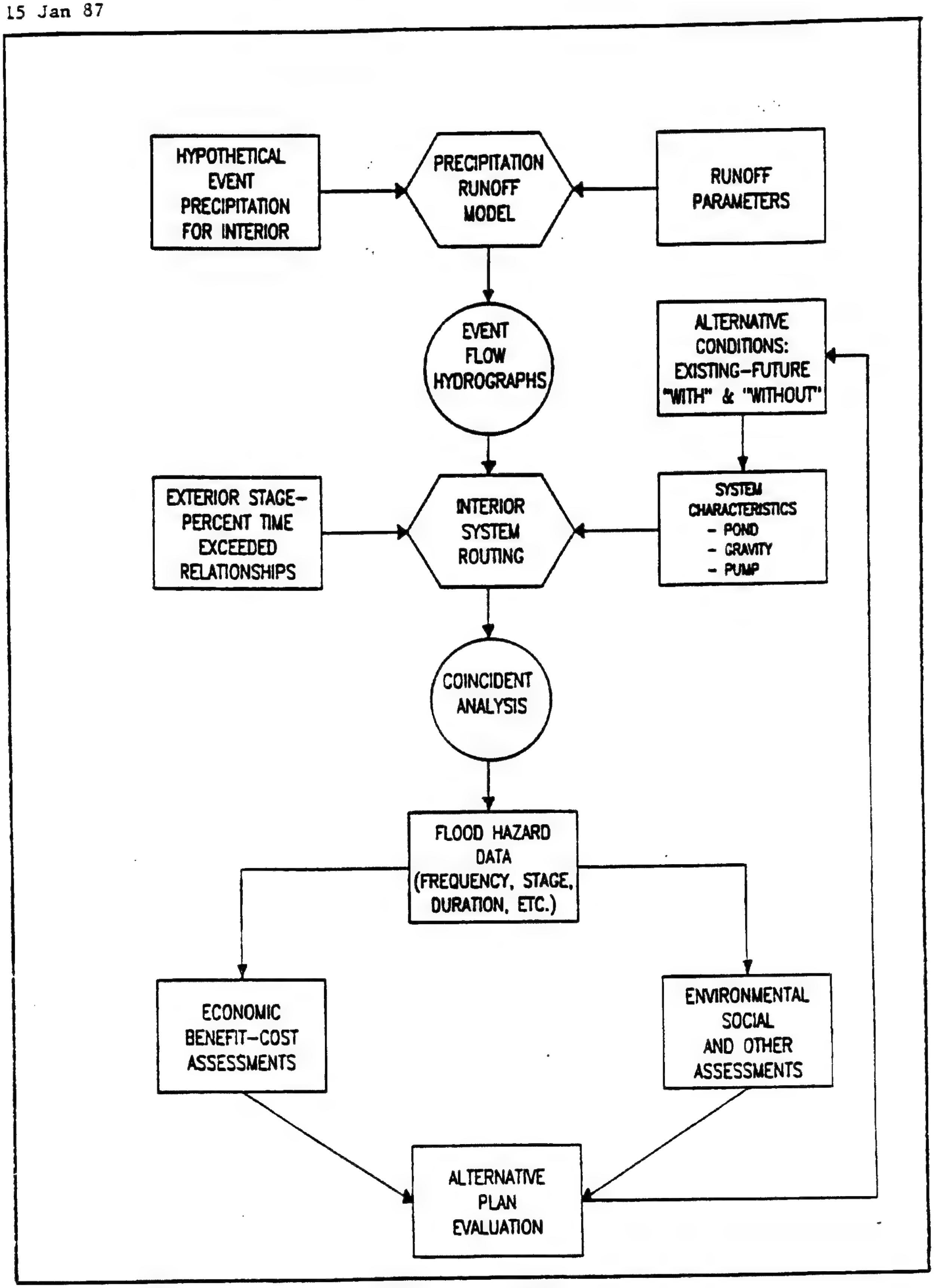


FIGURE 4.8 Coincident Frequency Analysis Schematic

desired locations. Hypothetical frequency storms are developed and applied to loss rate functions to obtain rainfall excess. The excess is applied to runoff transforms to produce runoff hydrographs which are subsequently combined and routed throughout the system. The results may be calibrated to observed events, flood damage information, or other items such as frequency of overtopping of roads and bridges.

(5) Stage-Frequency Functions. Stage-frequency functions are developed conventionally at interior locations not affected by the coincident interior flooding. For areas affected by coincident flooding (adjacent to the line-of-protection), the coincident frequency weighting method as previously defined and depicted in Figures 4.6 and 4.7 is applied to generate the stage-frequency relationship.

(6) Iteration of Alternative Plans. Repeat steps (4) and (5) for future without conditions and for each of the alternative plans. The results, along with the existing without conditions, are interfaced with evaluations performed by other study elements.

4-9. Procedure Selection.

a. The selection of procedures for hydrologic analyses of interior flooding is dependent upon the relationship of several factors, such as the nature of the study, characteristics of the study area, local institutional policies and practices, and experience of the analyst.

(1) Several of these factors are interrelated in that there is generally a relationship between the type of study and complexity of the physical system. Items of institutional policies and professional staff experience are often the overriding factors. It is also important to acknowledge that the several methods may be applied with varying amounts and accuracy of data so that it is possible to tailor the procedures to the stage of an investigation.

(2) Studies that seek general feature answers (e.g., early stages of Survey feasibility studies) for simple systems without complex coincident flooding may use conventional event analysis approaches. As the complexity of the coincidental aspects increased, the methods generally described herein become important. Where coincident events are clearly independent and the system is simple, the coincident frequency method is likely to be acceptable and more efficient for early to mid-stage planning investigations. Where coincident events are found to be less than completely independent, the continuous record simulation methods of period-of-record and discrete event analysis are generally acceptable methods. The multiple discrete events method is normally more adaptable to complex interior physical systems than is the commonly applied period-of-record. Although presently untested in interior analysis settings, the stochastic class of methods provides an opportunity to analyze simple systems where the historic record is short and/or there is need to evaluate operational strategies for several alternative hydrologic sequences other than those observed. As studies progress to design level detail, period-of-record procedures (for the

simpler systems) and multiple discrete events for the more complex systems are likely to be found as the appropriate methods.

b. The selection of a strategy for the hydrologic analysis that is efficent and adaptable to the several stages of a specific study is an important step toward obtaining viable results for the study. Due to the uniqueness of each study, the strategy should be custom designed, using analytical methods that are applicable to the study condition, the data, and the flood loss reduction measure assessment requirements.

CHAPTER 5

FLOOD LOSS REDUCTION MEASURES

5-1. General.

a. A broad range of potential flood loss reduction measures and performance standards should be addressed in planning investigations. These measures may be structural or nonstructural.

b. This chapter defines a broad array of measures for reducing flood related losses in interior areas. Emphasis is on the applicability of each measure as it relates to interior areas. Hydrologic analysis aspects of the measures are also presented. The measures have been classified for discussion purposes into:

(1) physical measures at line-of-protection,

(2) physical measures remote from line-of-protection, and

(3) nonstructural measures.

Physical measures at the line-of-protection include the main levee or wall (line-of-protection), gravity and pressure outlets; interceptor sewers, detention storage, and pumping facilities. Physical measures remote from the line-of-protection include diversions, channels, reservoirs (detention or retention basin), and interior levees or walls. Nonstructural measures include permenent measures for existing structures, measures to manage future development, and flood warning-emergency preparedness actions.

5-2. Physical Measures at Line-of-Protection.

a. Main Levees or Flood Walls. These measures comprise the line-of-protection that prevent direct flooding from rivers, lakes, or tidal waters. Implementation of these barriers creates the interior area by intercepting interior runoff and seepage at the line-of-protection.

(1) Major alignment considerations of the line-of-protection should be:

(a) minimization of the interior area contributing to runoff with proper locations of tie back levees, use of pressure conduits, and diversions out of the area;

(b) right-of-way and preservation of natural conveyance and storage areas; and

(c) minimization of volume of wave overtopping design freeboard of the line-of-protection so that if it occurs it will take place in a planned manner (e.g., least damaging, safe location).

(2) Minimum interior facility capacity through the line-of protection shall be provided as defined in paragraph 3-2b.

(3) Flood warning-preparedness plans should be considered as necessary components to the line-of-protection for urban areas. Associated actions, described later, may reduce the threat of catastrophic loss of life and property should failure occur in the line-of-protection.

b. Gravity Outlets.

(1) Gravity outlets are defined as culverts, conduits, or other openings (through the line-of-protection) that permit discharge of interior waters through the line-of-protection. The size of interior detention basins at the intake of the gravity outlet are based on the economic, environmental, and social aspects associated with the outfall ditch, gravity conduit, and ponding area analyzed as a collective system. The size selection must be based on the functional operation of the outlet for a range of expected events and not on a single design event.

(2) Where possible, gravity outlets should be located at or near where the line-of-protection intersects the natural or existing conveyance system or detention area. It is normally more feasible to provide one large gravity outlet than several smaller ones. This may require an interceptor system along the line-of-protection.

(3) Gravity outflow rating functions are normally required to assess the outlfow conditions of the major outlets. Rating functions should be developed for primary gravity outlets but may be combined for secondary outlets. Interior area discharge rating curves for gravity outlets are determined for a range of low and high tailwater conditions.

(4) Gravity outlet operational criteria are normally determined in the design level of study. Existing gravity outlet operation criteria should be obtained from the agency responsible for operating the interior system. Analysis of modified operation procedures is part of the plan formulation process. Normal operational criteria will be to release water to attempt to follow the lowering of the interior stages while maintaining a small positive head. The lag time between interior and exterior peak stages may be a critical factor in the operation specifications.

(5) Detention storage near the line-of-protection can reduce the capacity needed for outlets. Conveyance channels must be sized appropriately to assure that design flows are conveyed to gravity outlets, pumping stations, and/or detention basins at acceptable elevations. Flood forecasting measures may facilitate gravity outlet operation.

(6) The specific dimensions, invert elevation, headwalls and tailwalls and gate configuration of the gravity facility are normally considered to be determined by hydraulic design studies and are therefore not discussed in detail in this manual.

c. Detention Areas Adjacent to Line-of-Protection.

(1) The use of detention areas can significantly reduce the gravity outlet and pumping station size and costs. A detention basin may also increase the reliability of the system by providing additional time for appropriate operation before damaging water levels occur. A detention area may be natural or excavated sumps, or induced temporary ponding on vacant lots or areas, and streets and parks. Only a few areas are typically available or selected, and an interceptor system to collect and convey runoff along the line-of-protection is generally required.

(2) Topography, existing conveyance patterns, and land use usually govern the approximate locations of detention areas. Detention areas are normally located adjacent to the gravity outlet or pumping station, but may be remote from these facilities, connected by appropriately sized channels.

(3) Implementing nonstructural measures for surrounding structures to gain incremental storage versus increased capacity of gravity outlet or pumping facilities may be warranted in urban settings.

(4) Detention basins can be designed to be environmentally attractive and contribute to community social goals in urban areas when used as parks and open spaces during periods when not needed for runoff storage.

(5) Management of the functional integrity of the detention basin by preventing development encroachment and subsequent loss of storage capacity is critically important. Local agency agreements should specify requirements for maintenance of detention basin functional integrity throughout the project life.

(6) Hydrologic analyses should assess the impact of future development (volume of runoff) in terms of additional storage requirements of the detention basin.

d. Pump Stations.

(1) Pumps are designed to lift storm water and other interior flows over or through the line-of-protection to the exterior river, lake, or coastal area. Pump stations operate to reduce duration of ponding when flow through gravity outlets is precluded or impeded by high exterior stages. Consideration should be given to setting these elevations so that the pumps may be operated at least once or twice annually for maintenance and testing purposes. Pumps may be used for storm runoff, ground water and seepage, water accumulated from overtopping waves, and mixed flows with sanitary sewage. Implementation of pump stations is generally considered after analysis of gravity outlets and detention storage, since the initial and continuous operational, maintenance, and power costs of the stations are commonly significantly greater than that of other measures. For areas where the interior and exterior flooding is highly dependent (high likelihood of blocked drains coincident with interior flooding), pumping may be the only means to significantly reduce interior flood losses. For areas with independent interior and exterior flood conditions and where coincident flooding is not likely, pumping facilities may not be required.

(2) Pumping station justification is part of the planning process. The feasibility of pumping stations is based on economic and other considerations. In general, the without pump condition (with gravity outlets and detention storage implemented) must indicate adverse effects under present and the most likely future conditions. The implementation of a pumping station must reduce the adverse effects sufficiently to justify the construction and operation of the facility. Finally, it must be demonstrated that the implementation of a pumping station is the most effective means of reducing the adverse effects.

(3) Pumping stations are normally located adjacent to the line-of protection. Normally a larger capacity station is more desirable than several smaller ones. The station should be aligned in a manner which enables direct flow patterns into the forebay from the conveyance channel or detention areas. Gravity outlets may be offset if located near pumping stations where sufficient direct flow access to both the pump and gravity outlets is unavailable.

(4) Hydrologic analyses for planning investigations normally provides hydrologic data to determine the feasibility, location, and total capacity of the pumping stations.

(5) Hydrologic analyses performed under design studies typically refine and detail the hydrologic results developed in the planning investigations. The number and types of pumps are determined to provide the total capacity developed in the planning study. Pump on-off elevations are specified. Pumping heads for efficiency and starting assumptions are specified for various combinations of interior and exterior stage conditions. Hydrologic analysis of pumping stations at the design level must be closely coordinated with other engineering design activities.

(6) First or operation floor elevations of pumping stations should be, as a minimum, at or above ground level to provide convenient access to equipment, eliminate need for protection against ground water, and to simplify the ventilation of the operation areas. The consequence of exceeding pump design stage must be evaluated.

(7) Pumping and gravity outlet effects on exterior stages and operation of other downstream gravity outlets should be considered in locating, sizing, and designing the pumping station.

(8) The pumping station capacity in urban areas is generally determined by the physical performance of the facility and its effect on flood damage reduction, costs, and environmental and social factors. Station capacities in rural (agricultural type damage) areas are more commonly based on economic optimization.

e. Intercepting Sewers or Channels. These conveyance systems interconnect two or more existing sewers or channels within the line-of-protection for the purpose of conveying their flows to gravity outlets, pumping stations, or pressure conduits, for combined discharge

through the line-of-protection. Interceptor systems are designed to minimize the number of gravity outlets, pumping stations, and pressure conduits.

f. Pressure Conduits. Pressure conduits are pipes or closed conduits designed to convey interior flood waters through the line-of-protection under internal pressure. The inlet to the pressure conduit must be at a higher elevation than the river stage against which it functions. Some pressure conduits may serve as discharge lines for pumping facilities. The use of pressure conduits reduces the contributing interior runoff area and the magnitude and volume of flood waters that must be handled by other flood loss mitigation measures.

5-3. Physical Measures Remote From Line-of-Protection.

a. General. Measures are comprised of traditional structures such as channels, diversions, interior levees, and storage reservoirs remote from the line-of-protection. Their functional capability is therefore essentially the same as with any other planning or design investigations involving flood loss reduction measures. Consequently, only the interrelationship with other specific interior measures will be emphasized.

b. Channels. Conveyance channels reduce flood losses for damage centers remote from the line-of-protection and collect and transport runoff and other interior waters to gravity outlets, pumping stations, and pressure conduits. Where possible, channels should follow natural drainage and conveyance routes. When this is not possible, consideration should be given to locating channels near and parallel to the line-of-protection. Channels may be required in combinations with detention basins to connect with gravity outlets or pumping stations, and as exterior connections from the outlet works of gravity or pressure conduits or pumping stations to the river, lake, or ocean. The planning task is to approximately size and locate the channel system. The design task is to perform final design in terms of size, location, gradient, and auxilary control features of erosion protection and grade control.

c. Diversions. Diversions are used to transfer all or portions of the runoff from one location to another. Diversions may be made to collect flow for pressure conduits, to transfer flow out of the basin (reduce the contributing area), and to collect flow from areas to gravity outlets and pumping stations, thereby enabling fewer facilities. Diversions may be designed to permamently alter conveyance systems or to operate only for discharges above (and below) certain values. Diversions may be uncontrolled or operated as part of a coordinated system. Diversions may also be used to bypass flow around damage centers.

d. Remote Detention Areas or Reservoirs. Remote detention basins (reservoirs) have characteristics similar to those described for detention basins adjacent to the line-of-protection described in paragraph 5-2c. Bottomland detention basins may be natural sinks, oxbow lakes, or excavated sumps, or may be formed by levees. Hillside or bluff basins are really conventional reservoirs. Implementation of the remote basins may regulate flow to reduce the size of downstream interior flood loss reduction measures.

Damage reductions at several downstream locations may be achieved, in contrast to local protection works which are effective only at their individual damage center. Detention basins may also retain sediment from the hillside or bluff areas and thus eliminate it as an interior area problem.

e. Interior Levees and Walls. Interior levees and walls along conveyance channels may be implemented as local interior protection features. These barriers are normally lower in height than the conventional main levees and thus failure is less likely to result in catastrophic loss. If the barriers are of sufficient height, and damage potential from failure great, they are considered the same as the main line levees or walls. The interior levees may create secondary interior flooding problem that must be considered, though the magnitude would likely be minor. Implementation of these measures must meet criteria defined in Executive Order 11988" and other existing federal policy. Flood forecasting emergency-preparedness plans should be an integral part of implementation of interior levees and walls to reduce the potential for loss of life and property when the situation warrants. See criteria for main levees and walls described in paragraph 5-2a.

5-4. Nonstructural Measures.

a. Measure Categories. Nonstructural measures are categorized herein as:

(1) measures designed to permanently modify the damage susceptibility of existing structures,

(2) measures designed to manage future development and flood plain activities, and

(3) flood warning-emergency prepardness procedures. The measures warrant serious considerations in urban interior areas both as stand-alone measures and as a part of an integrated comprehensive plan.

b. Measures Which Permanently Modify Damage Susceptibility of Existing Structures.

(1) Several types of nonstructural measures are designed to permanently modify damage potential of existing structures. They include: flood proofing (seals, earthen dikes, and walls); raising existing structures; and relocation of occupants and/or structures (damage potential) from the specified threatened area. The measures are designed to modify the damage potential of an area. They are typically implemented on a localized scale (such as neighborhood) as opposed to structural and other types of nonstructural measures which often are designed to function for larger areas.

(2) Flood proofing and raising of structures to target elevations protect structures and contents until design limits are exceeded. The measures, applied to individual or small groups of structures are generally less environmentally disruptive than structural alternatives. The measures do not reduce damage to vital services (i.e., water, gas, power), streets, bridges, and landscaping, and (in most cases) only slightly reduce the social

impact and disruption associated with flood events. Seals, walls and dikes are often significantly less reliable than other permanent measures.

(3) Permanent relocation is defined as the removal of inhabitants and damage potential from the identified hazard area. Included are the physical moving of a structure and contents from the flood plain or demolition of the structure and moving inhabitants and contents to a new structure off the flood plain. Demolition of the structure may not be required if a compatible flood plain use of the structure can be identified.

(4) Flood proofing, raising, and relocation actions are generally more economically justified than structural measures when only a few structures are involved. Similarly, implementing nonstructural measures to a few structures to permit increasing the size of a detention basin may be more attractive than increasing the size of gravity outlets or pumping stations.

c. Measures Which Manage Future Development.

(1) Management of future development reduces losses by requiring flood plain development and activities to be operated or located in a specific manner commensurate with the flood hazard. Land use development can be controlled by regulations such as zoning ordinances, building codes and restrictions, taxation, or purchase of land in fee or by purchase of a flood easement. Structures not precluded from flood plain locations by these measures may locate on the flood plain if constructed and maintained to be compatible with the recognized flood hazard.

(2) Regulatory actions and land acquisition can also bring about new use of the flood plain. The measures are attractive from the perspective of managing development to reduce the future damage potential of the area and utilization of the flood plain for compatible purposes.

(3) Measures which manage future development are generally compatible with implementation of other structural and nonstructural measures. Regulatory actions may be incorporated as part of the agreements with local agencies or the local sponsor. For example, implementation of regulatory policies to preserve the storage and functional integrity of detention basins over the life of the project may be employed.

d. Flood Forecasting-Emergency Preparedness Plans.

(1) Flood emergency preparedness plans are comprised of flood emergency management actions and activities that reduce flood losses and minimize social disruption and assist in recovery and reoccupation of flooded areas. The measures should not be considered in lieu of other feasible permanent structural or nonstructural alternatives due to their temporary nature and uncertain reliability during flood episodes. Preparedness plans, however, should be considered as interim measures until other flood loss reduction measures are implemented; as companions to, or enhancements of such other measures; and as a means of minimizing the risk of loss of life, flood damage and social disruption if other methods are not feasible.

(2) Flood forecasting-emergency preparedness plans are generally compatible with other structural and nonstructural flood reduction measures. Implementation is more frequent in urban interior areas than in agricultural interior areas. Implementation of some level of flood forecasting-emergency preparedness actions is usually feasible even if other structural and nonstructural measures are not.

CHAPTER 6

SPECIAL TOPICS

6-1. General.

This chapter addresses special topics that are important to the planning, design, and operation of interior flood loss reduction systems. The topics are not necessarily directly related to hydrology, but hydrologic analysis assumptions and results are integrated into the concepts and material presented. The special topics discussed include performance standards, study considerations of urban and agricultural areas, flood damage evaluation concepts, and legal requirements.

6-2. Performance Standards.

Guidance for performance objectives for interior flood control projects are contained in ER 1105-2-20 (Reference 6) and ER 1105-2-30 (Reference 7). The Federal objective is to contribute to national economic development (NED) consistent with protecting the environment, pursuant to National environmental statutes, applicable executive orders, and other Federal planning requirements. Various plans in addition to the NED plan are to be formulated in a systematic manner. The NED plan is to be recommended for implementation unless the Secretary of a department or head of an independent agency grants an exception. Exceptions may be for potential catastrophic losses in urban areas (Reference 6) although catastrophic loss potential is not commonly found in urban interior areas. The NED plan is to be recommended in agricultural areas.

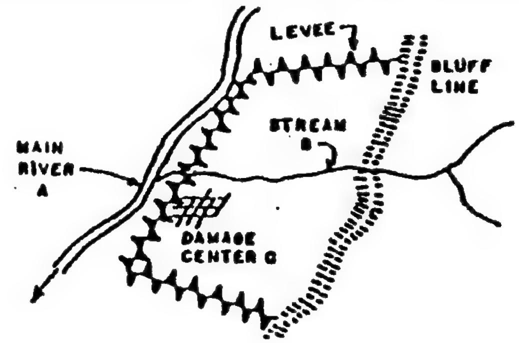
6-3. Study Concepts for Urban and Agricultural Areas.

There is no distinction in the planning and design study processes between urban and agricultural areas. There is also no direct distinction between performance standards for urban and agricultural areas. However, urban areas often produce through the study process the need for higher levels of protection than agricultural areas, because the consequences of flooding are likely to be of greater social concern and solutions may introduce more significant environmental problems. As a consequence, studies of urban interior areas often surface a more complex mix of alternatives and measures based on economic, social, and environmental factors than agricultural areas which typically yield systems that produce maximum net economic benefits. This does not preclude, however, the need throughout the study process for careful consideration of potential social and environmental impacts for agricultural areas.

6-4. Flood Damage Evaluation Concepts.

a. Flood damage evaluations of interior areas are complex. Figure 6.1 presents a conception of the damage frequency relationships for these conditions. The sketch represents the simplified condition of complete non-coincidence, but is nonetheless an important conceptualization.

NOTE: Example is for total non-coincidence of flooding between River A and Stream B.



CONDITION 1: WITHOUT CONDITIONS

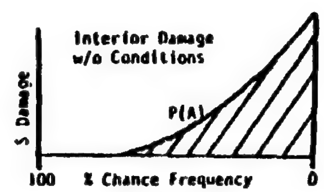
No levee or interior measures are in place. Total damage function for the potential damage center equals damage from the River A P(A) plus damage from interior flooding of Stream B P(B) (Joint probability Theorem).

CONDITION 2: WITH CONDITIONS

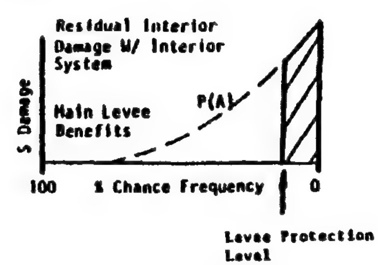
Implementation of main levee (2a) and interior flood loss reduction measures (2b). Benefits of main levee are equal to area under curve P(A) minus area under residual damage curve with levee in place. Benefits of interior system are equal to area under curve P(B) minus area under residual damage curve with interior system in place. Total benefits equal the sum of the two benefit values. Residual damage is similarly the sum of the residual values.

INTERIOR FLOODING FROM RIVER A

(1a)

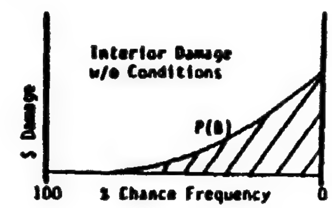


(2a)



INTERIOR FLOODING FROM STREAM B

(1b)



(2b)

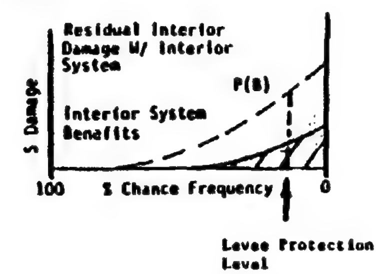


FIGURE 6.1 Flood Damage - Frequency Relationship Concepts

b. Condition 1 displays the total damage frequency function for damage center C for the without conditions. Without conditions are defined as without the main levee or wall and without any interior flood loss mitigation measures. The damage-frequency relationship for damage center C is equal to the sum of the individual functions for the river (A) and interior runoff (B). Each function is developed as if the other did not exist, then the two are simply added.

c. Condition 2 illustrates the resulting damage-frequency relationship for damage center C after the main levee or flood wall and interior flood loss reduction measures are implemented. The function generated in Condition 1a for without conditions is truncated at the level-of-protection. The figure for Condition 2b interior flooding illustrates the damage-frequency function (residual) at damage center C after implementation of proposed interior flood loss reduction measures, such as enlarged gravity outlets and/or pumping stations.

d. The benefit analysis summary is also conceptualized in Condition 2. The benefit is the area under the without conditions damage- frequency curve minus the area under the residual damage curve for both the main levee and the interior.

e. If instead of complete non-coincidence, complete coincidence had been sketched and analyzed, the benefits attributable to interior measures would be different. The benefits would be less by the hatched damage frequency block in 2b that represents events exceeding the levee protection level. This is because interior events more rare than the line-of-protection design level could not accrue interior benefits ... the design line-of-protection would have already failed.

6-5. Legal Requirements.

a. The capability of an interior flood loss reduction system to function over the project life must be assured. This often requires legally binding commitments from the local sponsors of the project to properly operate and maintain the system. Real estate interest required and specifications for operating and maintaining detention storage areas, pumping facilities, and conveyance networks, should be integral to all agreements for implementation of interior system of flood loss mitigation measures.

b. Those items that the local sponsor must provide as a condition for Federal participation in a local project are commonly referred to as the a, b, c's, and usually derived at least in part from Section 3, Public Law 738, 74th Congress - Flood Control Act of 1936.

"..Sec 3. That hereinafter no money appropriated under authority of this Act shall be expended on the construction of any project until States, political subdivisions thereof, or other responsible local agencies have given assurances satisfactory to the Secretary of War that they will (a) provide without cost to the United States all lands, easements, and rights-of-way necessary for the construction

> of the project, except as otherwise provided herein; (b) hold and save the United States free from damages due to the construction works; (c) maintain and operate all the works after completion in accordance with regulations prescribed by the Secretary of War:....."

This act has been subsequently ammended by Section 9 of the Water Resources Development Act of 1974 (Public Law 93-251). Regulations were prescribed by the Secretary of Army for maintenance and operation under Section 7, 58 Statutes 890; 33 USC 709.

c. 31 December 1970, Public Law 91-611 - River and Harbor and Flood Control Act of 1970, Section 221, provides that the construction of any water resources project must not be commenced until each non-Federal interest has entered into a written agreement to furnish its required cooperation for the project (84 Stat. 183, 42USC 1962d-5b).

d. The Federal and non-Federal participation in the plan should be developed and described in the authorizing document in a logical manner as follows:

(1) State the objectives and benefits expected to be achieved by the proposed plan. Provide specific information on the reduction in flood depths (elevation), duration, damages, etc., not just general statements.

(2) Describe all features of the plan necessary to achieve the objectives and benefits, not just the Federally constructed parts. This includes all structural and non-structural features, including any ponding areas and any other local actions needed (which local cooperation requirements will cover).

(3) Define the functional and operational requirements of each feature in specific terms: the necessary storage volume should the ponding areas; gravity drain capacity; gate closing elevations; pumping capacity; and the time equipment and manpower required to close the closure structures, etc.

(4) Present the capability of local interest to operate and maintain the plan. Also, present and discuss legal and financial capabilities and constraints that influence plan selection and/or operation. For example, it may be necessary to acquire a legal interest in ponding areas or channels where local interest does not have the legal capability to assure the required capacity by other means.

(5) Discuss operation and maintenance requirements in general. Provide a complete discussion of those requirements specific to the proposed plan not covered adequately in Title 33 CFR.

(6) In the section normally referred to as local cooperation, describe what locals must do as a condition to Federal participation. Describe project features and real estate interest that local organizations must provide. O&M requirements are usually referred to Title 33 CFR. If ponding areas are required, make a specific statement to this effect.

CHAPTER 7

REPORTING REQUIREMENTS

7-1. General.

Reporting requirements for the several types of studies are described in applicable Engineer Regulations. In addition hydrologic and hydraulic Engineering Technical Letters (ETL's) summarize the array of hydrologic data that must be presented for planning reports and suggest display formats. The goal of reporting (investigation findings) should be to describe in basic terms the nature of the flood problem, status and configuration of existing system, proposed system and alternatives, performance characteristics of proposed system, and important operation plans. This chapter suggests a general structure for reporting results of the hydrologic studies commensurate with the basic concepts of planning and design studies. Note that it is occasionally suggested that economic and other data be included so that the consequences of the hydrologic evaluations may be better judged.

7-2. Planning Considerations.

a. General. Hydrologic reporting requirements for feasibility investigation should include a description of the without conditions, alternative flood loss reduction plans analyzed, analytical procedures and assumptions used, and system implementation and operation factors influencing the hydrologic aspects of the study.

b. Existing System. The existing system will be defined and displayed schematically and by the use of maps, tables, and plates. The layout of the existing location of pumping stations, primary gravity outlets, detention storage basins, and conveyance networks shall be indicated on aerial photographs or other suitable cartographic materials. Important environmental aspects, damage locations, and cultural features will also be indicated.

c. Without Conditions.

(1) Physical characteristics and features of existing condition flood loss mitigation measures will be described and shown in tables and plates. Dimensions of gravity outlets, channels, and other measures shall be specified. Area capacity (storage-area-elevation) data of detention storage areas will be presented. Watershed and subbasin boundaries will be shown on a plate or map.

(2) The hydrologic analysis approach adopted, critical assumptions, and other analysis items for existing conditions will be described and illustrated as necessary. Historic and/or hypothetical storms, loss rate parameters, runoff transform parameters, routing criteria, and seepage will be described and depicted via tables and plates. Hydrologic flow characteristics, peak discharge, duration, frequency and velocity information will be presented for

important locations (damage centers, high hazard areas, locations of potential physical works). Schematic flow diagrams indicating peak discharges for a range of events will be included for urban areas. Presentation of several hydrographs of major hydrologic events, including precipitation and loss rates and runoff transforms, can greatly assist in explaining the nature of flooding.

(3) Future without conditions will be described as they impact on hydrologic conditions, assumptions, and procedures. Changes in runoff and operation resulting from future conditions will be described in terms similar to the existing conditions description of paragraph 7-2.c(2). Procedures adopted for parameter estimation for future conditions will be described.

d. Hydrologic Analysis of Alternatives.

(1) The location, dimensions, and operation criteria of components of the alternative plans will be described and depicted on tables and plates. Locations of the alternative measures or plans will be displayed on aerial photographs and/or other cartographic materials so that comparisons with existing conditions may be readily made. Impacts of measures and plans on flood hydrographs (peaks, durations, velocities) for a range of events will be provided at similar locations as for without conditions. Display of the effects on hydrographs of paragraph 7-2.c(2) above should be included. Display of residual flooding from large (one-percent chance and Standard Project flood) events is required. Also include tables of pumping rates that impact on flood hydrographs and stages.

(2) The hydrologic description of the various alternative plans will include a description of the required local agreements and maintenance requirements. The hydrologic consequences of failure to adequately fulfill these requirements will also be presented.

7-3. Design Considerations.

a. Hydrologic material presented in the design documents (GDM and FDM) will describe in detail the hydrologic system, and any refinements of sizes, performance standards, and operation criteria from the feasibility study. The hydrologic requirements for the GDM are specified in ER 1110-2-1150 (10) and summarized in the following paragraphs.

(1) Present the basis and results of hydrologic and hydraulic studies requred to determine the functional design and real estate requirements of all water control projects.

(2) Hydrologic studies should include: discharge-frequency relationships; Standard Project and perhaps the Probable Maximum floods; stage-discharge relationships; flow duration; inundation limits; freeboard determinations; existing and post-project sedimentation; water quality and groundwater conditions; project regulation plan; real estate guide taking line elevations; criteria for relocations and other flowage right determinations; and criteria for guidance and support of local assurance requirements.

(3) The residual flood condition with the selected plan in place will be described. As a minimum, the information will include the following: warning time of impending inundation; rate-of-rise, duration, depth andvelocity of inundation; delineation of the best available mapping of the flood inundation boundaries; identification of potential loss of public service; access problems; and potential damages. This information will be developed for each area of residual flooding for historic, Standard Project Flood, one- percent chance flood and the flood event representing the selected level of protection. This information will be incorporated into the operation and maintenance manual for the project and disseminated to the public.

(4) Hydraulic study results to be presented include: water surface profiles; headloss; velocity; pressure conditions; structural sizing for design capacities; water control facilities; energy dissipating facility details; and erosion control requirements.

(5) For coastal projects, tidal fluctuations and overtopping conditions should be defined.

b. Feature design memorandum reporting requirements for hydrologic analyses are summarized below (Reference 10):

(1) A summary of project data applicable to the feature being presented.

(2) Basic data and criteria used in the design, referring to the GDM, applicable engineer manuals and regulations, guide specifications, and other sources of criteria.

(3) Design drawings, sketches, charts, diagrams, maps, profiles, or other graphic data necessary to illustrate the design. The maps should clearly identify all places and names mentioned in the text of the design memorandum.

(4) Results of investigation, analyses, and engineering computations made for the design of essential parts or items. The information will include: formulas, methods, and assumptions used to determine pertinent design features, flow characteristics, and discharge capacities. Also to be included are design water surface profiles, coefficient and discharge curves, and other plotted data or tabulations. Hydrologic aspects of physical model tests should be included when the design is based on a model study.

APPENDIX A

REFERENCES

1. Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies, Federal Register, March 10, 1983.

2. Engineering Manual 1110-2-1405, "Flood Hydrograph Analysis and Computations." 1959. U.S. Army Corps of Engineers.

3. Engineering Manual 1110-2-1408, "Routing of Floods Through River Channels." 1960. U.S. Army Corps of Engineers.

4. Engineering Manual 1110-2-1913, "Design and Construction of Levees." 1978. U.S. Army Corps of Engineers.

5. Engineering Regulation 1105-2-10, "Feasibility and Preconstruction Planning and Engineering Studies." 1982. U.S. Army Corps of Engineers.

6. Engineering Regulation 1105-2-20, "Project Purpose Planning Guidance." 1982. U.S. Army Corps of Engineers.

7. Engineering Regulation 1105-2-30, "General Planning Principles." 1982. U.S. Army Corps of Engineers.

8. Engineering Regulation 1105-2-40, "Economic Considerations." 1982. U.S. Army Corps of Engineers.

9. Engineering Regulation 1105-2-50, "Environmental Resources." 1982. U.S. Army Corps of Engineers.

10. Enginering Regulation 1110-2-1150, "Engineering after Feasibility Studies." 1984. U.S. Army Corps of Engineers.

11. Executive Order 11988, "Flood Plain Management." 1977.

12. Hydrologic Engineering Center, "Hydrologic Analysis of Ungaged Watersheds Using HEC-1," 1982. U.S. Army Corps of Engineers.

13. National Environmental Policy Act, 1969.

14. Planning Guidance Notebook, "Multiobjective Planning Study Management," 1982. U.S. Army Corps of Engineers.

APPENDIX B

INTERIOR AREA ANALYSIS EXAMPLES

This Appendix presents example procedures for performing interior area coincident flood frequency analyses at outlets through the line-of-protection. The examples are for: (1) period-of-record; (2) multiple discrete events; and (3) coincident frequency analyses procedures, Exhibits 1, 2, and 3, respectively. The examples emphasize the coincident analysis concepts for planning feasibility studies. Hydrologic and hydraulic aspects of interior areas are described only in the detail necessary to understand the overall analysis strategy. The reader should not apply these procedures without complete understanding of the needs and peculiarities of the study area under investigation. Study strategies presented herein would likely require some modifications for application to other study areas.

EXHIBIT B1

PERIOD-OF-RECORD ANALYSIS EXAMPLE

B1-1. Purpose.

This exhibit describes with a case example the period-of-record analysis procedure for performing hydrologic studies of a leveed interior area. The example emphasizes concepts in a feasibility study setting. The reader should be familiar with the material in paragraph 4-5 prior to studying this example.

B1-2. General Study Background.

a. The Corps of Engineers is performing a feasibility study of remedies for interior flooding of the Nelson Drainage and Levee District, an agricultural area in the Smith River Valley. The area is protected from direct river flooding to a two-percent chance exceedance frequency event by a main levee and a tie back levee (See Figure B1.1). The interior area consists of 5,000 acres in the Smith River flood plain and receives runoff from about 300 acres of adjacent hill land. Runoff is conveyed through the interior area by a network of lateral ditches and main channels. The only outlet for interior runoff is an existing gravity outlet comprised of double 60 inch diameter culverts through the line-of-protection. During large events water from the Olson Pond Drainage and Levee District overflows into the study area.

b. Agricultural crop flood damage has resulted from ponding of local runoff adjacent to the line-of-protection. Damage occurs during prolonged periods of blocked gravity outflow caused by high river stages. Flooding commonly occurs in the spring months. Approximately one-half of the area has been inundated three times during the past 10 years.

B1-3. Study Strategy.

a. Reconnaisance level studies found that significant flood damage potential existed in the interior areas and that it is justified to study alternative flood loss reduction plans. These plans include combinations of modifications to ditches, channels, and gravity outlets, and the installation of pumping facilities. Period-of-record analysis procedures are used to develop hydrologic data for agricultural flood damage assessments, optimal sizing of additional gravity outlets and pumping facility capacities, and selection of pump operating criteria. Data requirements and hydrologic analysis procedures used in the plan formulation portion of the study are described in paragraph 4-5 Period-of-Record Methods and shown schematically on Figure 4.2.

b. Period-of-record analysis procedures are applicable because of the availability of long-term precipitation and exterior stage data, the agricultural nature of flood damage, and the simplistic nature of the interior drainage pattern at the major damage center. Flood damage evaluations may be computed directly from each historic event by accounting for season, magnitude, and duration of the event. Annual pump operation times may also be directly calculated.

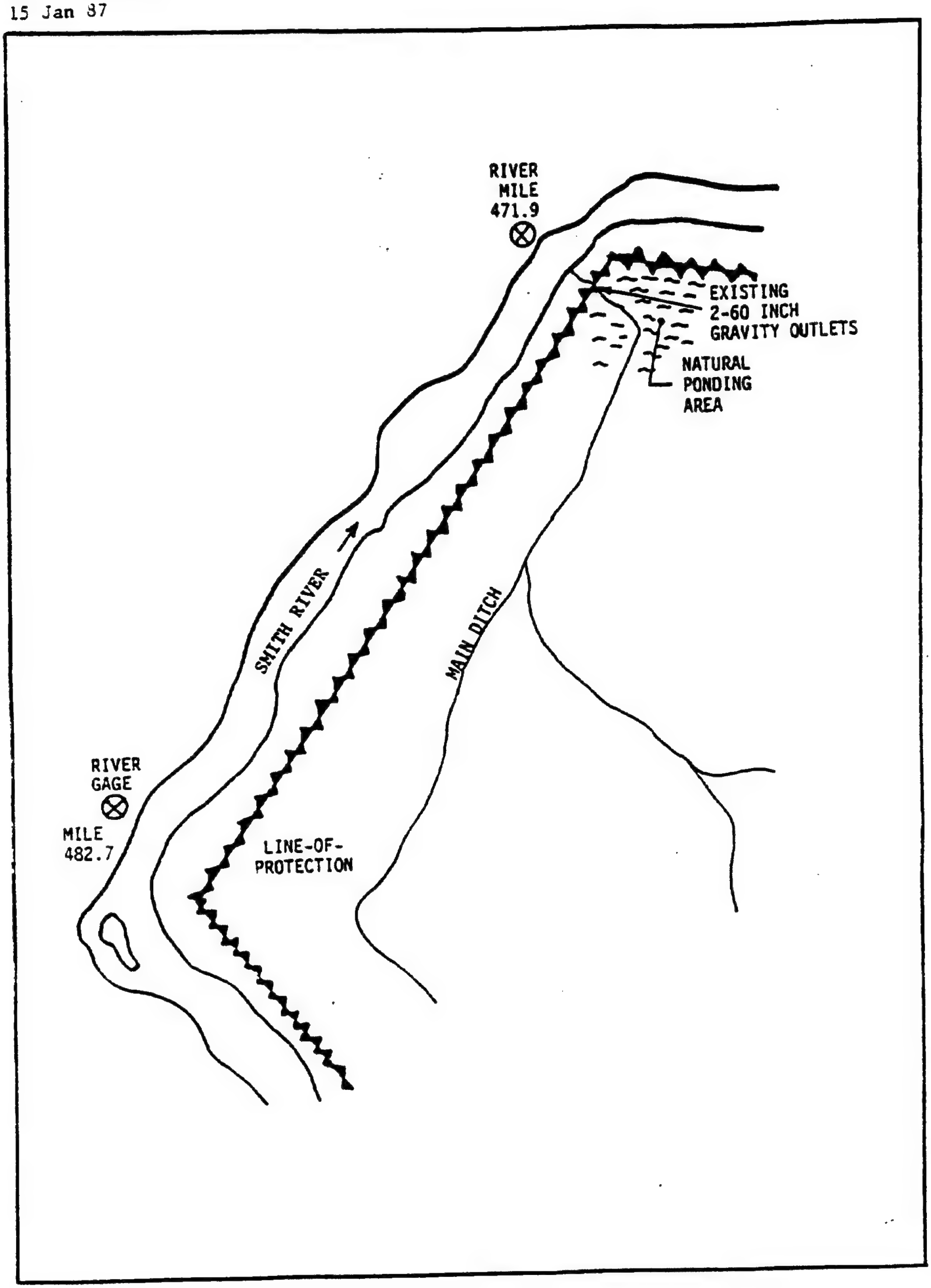


FIGURE B1.1 Study Area Map

c. The period-of-record analysis is performed for with and without proposed improvement for existing and future conditions. The existing condition minimum facility (reference paragraph 3-2) is assumed as the gravity outlet presently in place. The formulation strategy involves initial evaluations of additional gravity outlet capacity (ultimately found not feasible) and subsequent analysis of various pumping facility sizes. A period-of-record assessment is performed for the existing conditions without a proposed improvement project, and for each gravity outlet and pumping facility size. Since no change in the agricultural area is projected throughout the project life, future hydrologic conditions are the same as existing conditions.

B1-4. Hydrologic Analysis Methods.

a. General. Analysis of the interior area is based on data requirements for period-of-record precipitation-runoff response parameters, ponding area geometry, seepage, overflow runoff into the study area, gravity outlet and pumping capabities, and exterior stage conditions. Calculations involving these parameters are performed at 24-hour intervals for the 50-year period-of-record selected for analysis. Interior hydrographs are subsequently generated and routed through the line-of-protection. The resulting interior stage-hydrographs are used in damage calculations. The formulation strategy analyzed several sizes of gravity outlets and pumping station capacity.

b. Historic River Stage Data. Historic river stage data are required at the gravity outlet and proposed pumping facility location (river mile 471.9) to perform the period-of-record coincident routings through the line-of-protection. The period-of-record stage data are developed from the historic record of the nearby streamgage (river mile 482.7) using a river transfer relationship (Table B1.1). The transfer relationship is derived by determination of differences in elevations of similar water surface profiles between the two locations

Table B1.1
River Elevation Adjustment Relationship

Elevation at River Gage Mile 482.7	Elevation at Interior Pond Gravity Outlet River Mile 471.9
368.0	361.2
370.0	363.1
372.0	365.1
374.0	367.0
376.0	369.0
378.0	370.9
380.0	372.7
390.0	382.2
400.0	391.8

c. Precipitation Data. A daily time interval was selected as appropriate for this period-of-record analysis. Review of exterior stage and daily precipitation records obtained on magnetic tape from the U.S. Geological Service and National Weather Service, respectively, indicate an analysis period of up to 50-years may be used. This period-of-record length is considered adequate for the agricultural study area. Daily rainfall values were obtained from National Weather Service data at three nearby raingages and used to develop a rainfall distribution pattern for the study area. This is accomplished by weighting the respective contribution of each raingage based on the distance of the gage from the center of the study area.

d. Rainfall-Runoff Analysis. The daily time interval and interest in volume (instead of peak flow) of inflow into the interior ponding area enables the adoption of a simplified rainfall-runoff analysis procedure. The generated daily precipitation data for the study area is adjusted by seasonal loss factors to obtain rainfall excess (Table B1.2). The excess values are multiplied by the drainage area to obtain the volume of inflow into the interior ponding area. Channel routing is not required due to the small basin and daily time interval of analysis.

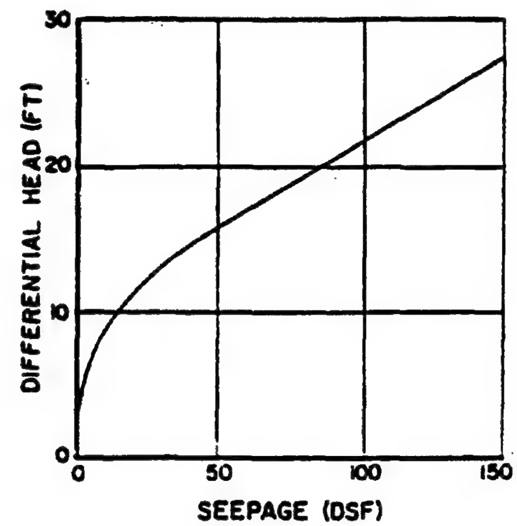
Table B1.2
Seasonal Runoff Factors
for Rainfall Excess Calculations

Season	Factor
Winter (Dec - Feb)	.55
Spring (Mar - May)	.73
Summer (Jun - Aug)	.65
Fall (Oct - Nov)	.70

e. Seepage. A secondary inflow into the ponding area is seepage which occurs through or under the line-of-protection during high exterior river stages. A relationship of seepage rate versus the differential head between the interior pond and exterior river stage is estimated based on pumping tests of interior relief wells installed for levee stability and estimates by foundation engineers obtained from similar studies. The total seepage includes inflow adjacent to the levee, beyond the levee, and from relief wells. A one day lag time is used to simulate estimated transmission rates. Figure B1.2 shows the seepage rate versus head relationship.

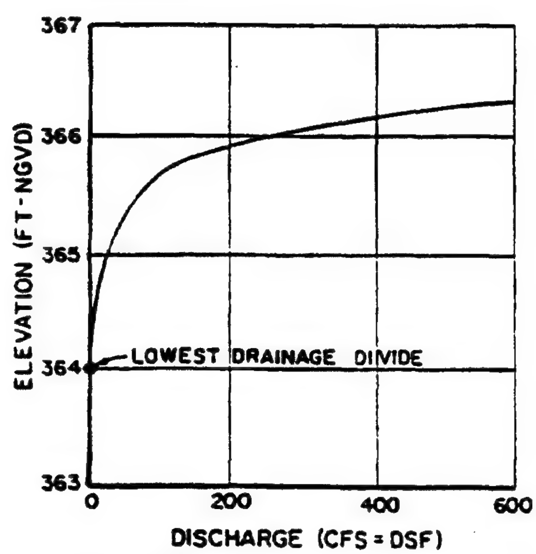
f. Overflow. The rating curve developed to characterize the overflow of water from the study area into adjacent areas is shown on Figure B1.3. The relationship is based on a normal depth rating curve for the cross-section overflow areas.

g. Interior System Characteristics. The physical characteristics of the interior system defined for the analysis are the ponding area, conveyance ditch systems, gravity outlets, and pumping stations. Their locations are shown on Figure B1.1.



Day-second-feet (DSF) = 1 cubic-foot per second for 24 hours

FIGURE B1.2 Head vs. Interior Seepage Relationship



Day-second-feet (DSF) = 1 cubic-foot per second for 24 hours

FIGURE B1.3 Interior Ponding Area Overflow Relationship

(1) Ponding Area. The interior ponding area is adjacent to the line-of-protection at the gravity outlet and proposed pumping facility location. The main ditch flows into the ponding area. The area is defined for analysis by an elevation-storage relationship shown in Figure C1.3. The major damage to crops in the interior area occurs from ponding in this area.

(2) Conveyance. The small lateral interior ditches flow into the main channel of the interior system which conveys flood waters to the ponding area. Inflow to the ponding area is governed by the conveyance capacity of the channel. Figure B1.4 shows the channel inflow rating curve (elevation-discharge relationship). The inflow is dependent on the elevation of the ponding area.

(3) Gravity Outlets. The double 60 inch gravity outlet conveys water from the ponding area through the line-of-protection. The outlets function only for a positive head conditions (interior pond elevations are higher than the exterior river elevation). The gravity outlet rating functions are plotted for a range of possible flow conditions associated with ponding area and river elevations. Figure B1.5 shows the rating function for the double 60 inch gravity outlet in the study area.

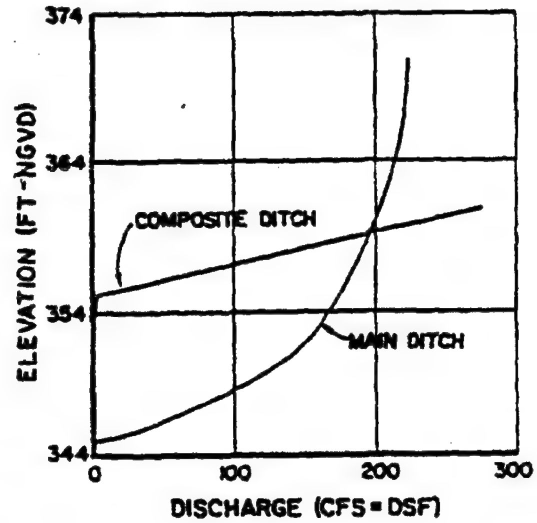
(4) Pumping Facilities. Alternative pumping facility capacities are analyzed as part of the feasibility study. The pump location is adjacent to the ponding area. The pump head-capacity relationship is based on information supplied by pump manufacturers (Table B1.3). Pump start and stop elevations are based on the proposed plan of operation.

Table B1.3
Pumping Facility Criteria
(75 cfs Pump)

Head (Feet)	Efficiency (Percent)
0	100
10	100
15	97
20	93
25	88
30	80
35	50

Start Pump Elevation 348.0
Stop Pump Elevation 346.5

h. Interior Ponding Routing. The result of the period-of-record analysis is a continuous stage hydrograph of the ponding area adjacent to the gravity outlets and proposed pumping facility. The routing is performed by balancing the inflow, outflow, and ponding level for each day of the period of record. Inflow may occur from rainfall runoff, seepage, and overflow from the Olson



Day-second-feet (DSF) = 1 cubic-foot per second for 24 hours

FIGURE B1.4 Interior Area Ditch Rating Curve

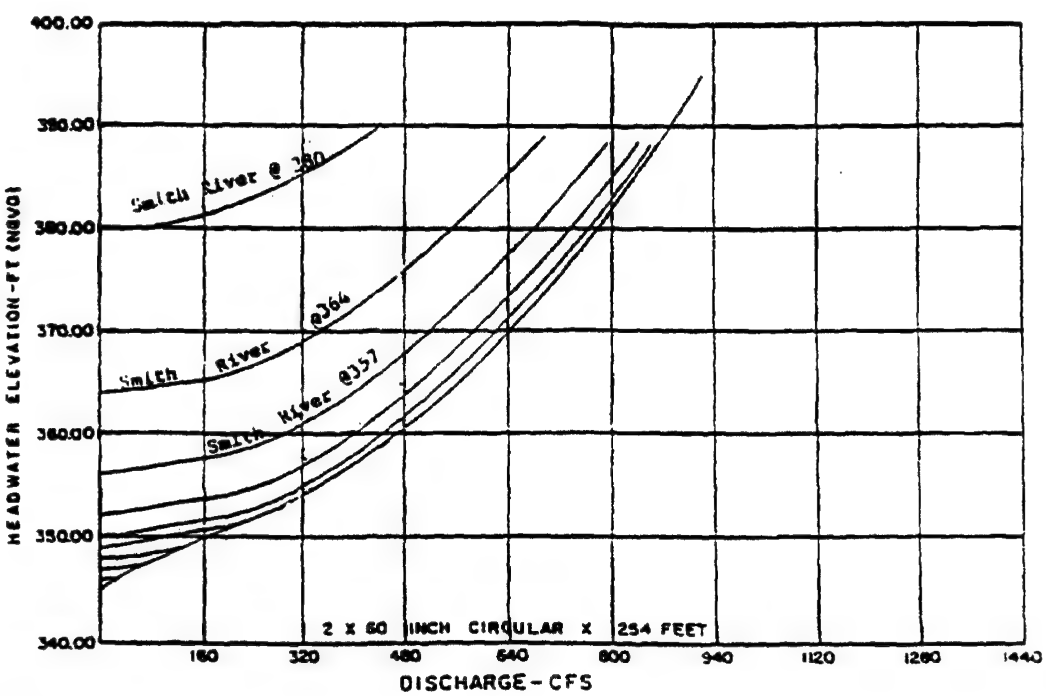


FIGURE B1.5 Gravity Outlet Rating Curve

Ponding Drainage and Levee Districts. Outflow may result from gravity outlets, when the exterior river elevations are lower than the interior ponding stage, and from pumping. The volume of inflow that exceeds outflow is stored in the ponding area.

The period-of-record interior ponding stage may be estimated using the following procedure:

(1) Calculate runoff, seepage, and overflow inflow into the ponding area and add the total volume to the present storage to determine highest possible ponding level;

(2) Calculate the maximum outflow (based on physical constraints) to determine the lowest possible pond level for the period;

(3) Assume a ponding level within the range possible;

(4) Calculate outflow based on interior and exterior stage conditons and associated gravity outflow and pumping capacities;

(5) Reiterate steps (3) to (4) for successive ponding level approximation until the end-of-period storage from two successive iterations varies by less than a specified tolerance;

(6) Continue steps (1) through (5) for the next time interval until the entire period-of-record is analyzed; and

(7) Repeat steps (1) through (6) for other alternatives.

The interior analysis procedure may be performed using a computer program to simulate interior inflows, interior stage conditions, and hydrograph routings through the line-of-protection. Table B1.4 shows an example computation sequence for the 8-17 May 1973 portion of the 50-year period-of-record. The procedure is repeated for each time interval for the entire record. The computer simulation model enables several alternatives of gravity outlets and pumping facility sizes to be analyzed in a single computer run.

i. Calibration Procedure. The period-of-record hydrologic simulation model is calibrated to historic high water marks and the observed frequency of flooding at roads, bridges, structures, landmarks located in the ponding area. Adjustments are made to the initial runoff loss rate parameters and lag time to calibrate the results (peak stages and runoff volumes) to the observed data.

B1-5. Summary.

a. The period-of-record method of analyzing the coincident interior flooding of leveed or walled areas simulates the physical process of inflow, outflow, and ponding area storage and outflow over time. The procedure is especially applicable to analysis of interior systems where the primary concern is at a ponding area adjacent to the line-of-protection.

Table B1.4

Period-of-Record Daily Analysis Example
(8-17 May 1973 Portion of 50-Year Record)

Date	Rainfall Excess (Inches)	River Elevation (NVGD)	Ponding Area Area-Capacity Data: Elev (NVGD)	Ponding Area Area-Capacity Data: Area (Acres)	Ponding Area Area-Capacity Data: Storage (DSF)	Inflow Into Ponding Area: Runoff (DSF)	Inflow Into Ponding Area: Seepage (DSF)	Inflow Into Ponding Area: Overflow (DSF)	Outflow From Ponding Area: Gravity (DSF)	Outflow From Ponding Area: Pump (DSF)	Outflow From Ponding Area: Overflow (DSF)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
8 May 1973	.01	370.8	358.9	675	746	2	25	0	0	72	0
9 May 1973	.32	371.5	359.0	715	785	85	25	0	0	71	0
10 May 1973	.82	371.5	359.3	889	958	216	28	0	0	71	0
11 May 1973	.01	371.8	359.2	846	916	2	27	0	0	71	0
12 May 1973	0	372.0	359.2	804	874	0	29	0	0	71	0
13 May 1973	0	372.0	359.1	762	832	0	30	0	0	71	0
14 May 1973	0	371.8	359.0	721	791	0	30	0	0	71	0
15 May 1973	0	371.5	358.9	679	749	0	30	0	0	71	0
16 May 1973	0	371.3	358.9	636	707	0	29	0	0	71	0
17 May 1973	0	370.5	358.8	554	663	0	28	0	0	71	0

(1) Calculation time interval (24 hours shown as a date) of the period-of-record used for analysis;
(2) Rainfall excess over study area determined by subtracting losses from the rainfall value associated with each time interval;
(3) River elevation at the gravity outlet;
(4) Interior ponding elevation for time period determined by balancing inflow, outflow and storage of the ponding area;
(5) Area flooded associated with interior ponding elevation;
(6) Storage associated with interior ponding elevation;
(7) Volume of interior inflow to ponding area resulting from rainfall excess;
(8) Volume of seepage inflow to ponding area;
(9) Volume of overflow from adjacent areas into study area;
(10) Volume of gravity outflow from ponding area;
(11) Volume of flood water evacuated from interior ponding area by pumping; and
(12) Volume of flood water which overflows from study ponding area into adjacent area.

NOTE: Day-Second-Feet (DSF) = 1 cubic feet per second (cfs) for 24 hours.

b. The example described here is typical of a single pond analysis for an agricultural area adjacent to the line-of-protection. Exterior stages are determined by transfer of a historic record from a nearby streamgage. The runoff analysis is greatly simplified and uses a daily time interval but is sufficiently accurate for the volume accounting required for this area. Other inflow simulated are overflow from adjacent interior areas (evaluated separately) and seepage. Criteria for operating gravity and pumping outflow are dependent on the differential interior and exterior stages.

c. The flood loss reduction measure formulation process requires analysis of various sizes of gravity outlets and pumping facilities. Alternative gravity outlet invert elevations and pump on-off operation conditions are also evaluated. These assessments require additional analyses of the alternatives for the period-of-record.

EXHIBIT B2

MULTIPLE DISCRETE EVENTS

B2-1. Purpose.

This exhibit describes a case example of the multiple discrete event analysis procedure for performing hydrologic studies of a leveed interior area. The example emphasizes development of a discharge-frequency relationship for flood damage evaluation requirements of a feasibility study. The reader should be familiar with the material in paragraph 4-6 prior to studying this example.

B2-2. General Study Background.

a. The Corps of Engineers is performing a feasibility investigation of flood loss reduction measures of the Hartgrove Drainage and Levee District. The area is primarily agricultural, but also includes the community of Wilson Grove located adjacent to the line-of-protection (see Figure B2.1). The drainage and levee district is protected from direct flooding of the Smith River to a 2-percent chance exceedance frequency event by a main levee and two tie back levees (see Figure B2.1). A single 54 inch diameter gravity outlet enables evacuation of interior floodwaters through the line-of-protection during low river stages.

b. The interior conveyance system consists of a complex network of lateral ditches connected to the main interior ditch which flows to the gravity outlet. Interior flooding along the lateral and main ditches is common when the gravity outlet is blocked by high river stages. Seepage also contributes to the interior flooding adjacent to the levee during prolonged high river stages.

B2-3. Study Strategy.

a. Reconnaissance level investigations found that significant flood damage potential exists in the Hartgrove Drainage and Levee District and that a survey study is justified to investigate alternative flood loss reduction plans. These plans include combinations of modifications to ditches, channels, and gravity outlets, and the installation of pumping facilities. Multiple discrete event analysis procedures are used to generate hydrologic data for both agricultural and urban (Wilson Grove) flood damage evaluations, optimal sizing of additional gravity outlets and pumping capacities, and selection of pump operation criteria. NOTE: Only the procedures required to develop the existing condition discharge-frequency relationship for Wilson Grove are described. Data requirements and hydrologic analysis procedures used in the plan formulation portion of the study process are described in paragraph 4-6 Multiple Discrete Event Methods, and schematically depicted in Figure 4.4.

b. The multiple discrete event analysis is performed for with and without existing and future conditions. The existing condition minimum facility

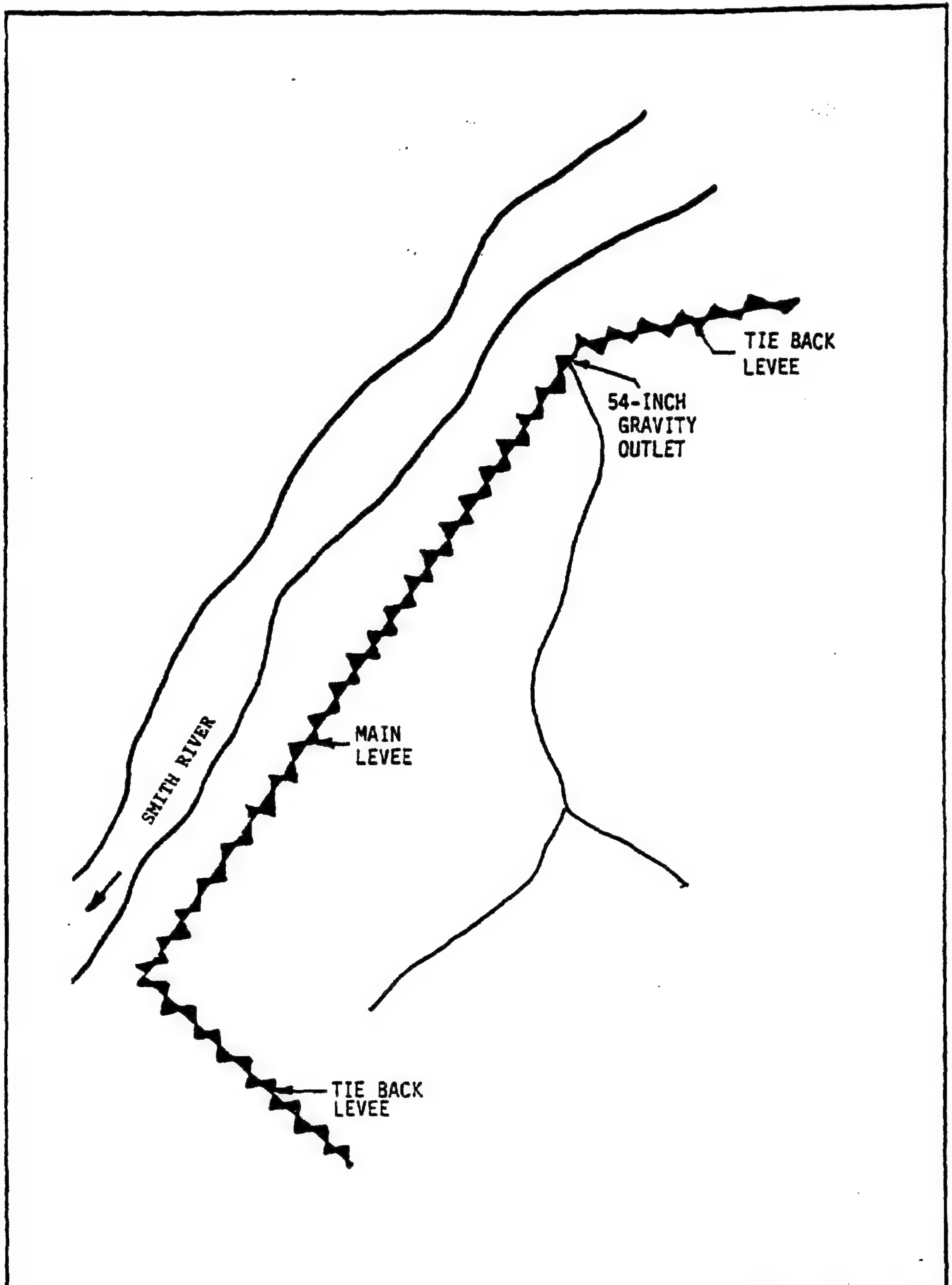


FIGURE B 2.1 Study Area Map

(reference paragraph 3-2) is assumed as the gravity outlet presently in place. The formulation strategy involves the analysis of additional gravity outlets and a range of pumping capacities. The feasibility of increased ditch conveyance is analyzed for flood damage reduction and to ensure proper volume of flood waters reach the proposed pumping plant. A series of multiple discrete events were analyzed for existing with and without project conditions.

c. The hydrologic analysis strategy for developing discharge-frequency relationships for evaluation of flood loss reduction measures for Wilson Grove is:

(1) Obtain historic rainfall and runoff (discharge and elevation) data for important events,

(2) Analyze interior flood events associated with blocked or partially blocked gravity outlet conditions,

(3) Analyze historic interior flood events associated with unblocked gravity outlet conditions,

(4) Develop annd combine the discharge-frequency relationships resulting from (2) and (3) using the joint probability theorem, and

(5) Analyze project proposal impacts on the hydrologic systems repeating steps (2) and (4).

B2-4. Hydrologic Analysis Methods.

a. General. Analysis of the interior area is performed based on data requirements for runoff response parameters, ponding area geometry, seepage, gravity outlet and pumping capacities, and exterior river stage conditions. Calculations are made for both the blocked and unblocked gravity outlet conditions. Runoff hydrographs are developed, combined, and routed throughout the interior system, and ultimately through the line-of-protection. The Wilson Grove urban damage at the gravity outlet is calculated using a discharge-frequency relationship developed from the joint probability theorem for blocked and unblocked conditions. The hydrologic analysis strategy is performed for the with and without existing and future project conditions evaluations.

b. High Exterior Stage Analysis. Historic river records of stage-discharge relationships are used to identify exterior events that might close the gravity outlet and therefore potentially produce interior flooding. The data were obtained from a nearby streamgage and transferred to the gravity outlet location by adjusting for the slope in the profile. The Smith River stage data were obtained for the period of 1934 through 1976. Thirteen events were identified as exceeding the normal gravity outlet closure stage (no interior runoff flooding). The events included all major river floods in the period-of-record. Table B2.1 lists pertinent data associated with each of the events.

Table B2.1
High Exterior Stages
Maximum Smith River Flood Events
(Period-of-Record 1934 Through 1976)

	Beginning Date of Flood Event	Duration In Days (1)	Peak W. S. Elevation at Gravity Outlet Stage (ft)	Peak W. S. Elevation at Gravity Outlet Elev. (NVGD)	Total Interior Rainfall (Inches)
1.	2 Mar 1973	131	45.6	350.4	37.82
2.	13 Jun 1969	42	39.2	344.0	3.34
3.	15 Mar 1962	62	36.2	341.0	6.43
4.	6 May 1961	27	39.5	344.3	8.62
5.	30 Mar 1960	84	38.4	343.2	7.79
6.	12 Mar 1952	81	38.3	343.1	13.86
7.	6 Jun 1951	61	41.8	346.6	8.23
8.	21 Mar 1948	38	37.8	342.6	8.63
9.	27 May 1947	108	41.8	346.6	6.86
10.	5 Mar 1945	122	38.7	343.5	20.48
11.	12 Apr 1944	99	42.8	347.6	15.26
12.	9 May 1943	76	42.4	347.2	15.67
13.	5 May 1935	79	36.4	341.2	17.62

(1) Days above gravity outlet closure stage. Closure stage corresponds to the river elevation that would result in interior damage if outlet was open and no interior runoff flooding was occurring simultaneously.

c. Interior Rainfall Analysis. Interior rainfall analysis is performed for two conditions. The first includes estimating the historic rainfall coinciding with the 13 exterior flood events. The daily totals are shown in Table B2.1. Daily totals are used due to the long duration of river flooding and lack of hourly records until 1948. The second condition is intense historic rainfall periods (over a specified duration) that might induce flooding during unblocked or low exterior river conditions. A seven day duration was adopted to insure sufficient runoff timing and volumes throughout the interior. Inspection of three nearby recording rain gages found 12 storm events of sufficient intensity to cause potential flooding and damage to the interior area. Table B2.2 lists the rainfall data associated with these 12 events. A period-of-record from 1948 to 1974 is adopted since a 6-hour time interval of analysis meets the appropriate hydrologic analysis requirements for the interior analysis during unblocked gravity outlet conditions.

Table B2.2
Low Exterior Stage

Maximum 7-Day Rainfall (1)
(Period-of Record 1948-1974)

	Date of Beginning of Storm	Total Storm Precipitation Measurements in Inches		
		(2) Raingage 1	(3) Raingage 2	(3) Raingage 3
1.	21 Jan 1949	8.51	5.29	5.12
2.	2 Oct 1949	5.62	6.05	6.13
3.	1 Jan 1950	8.01	6.47	6.89
4.	12 Aug 1950	2.61	5.84	6.60
5.	9 Aug 1952	7.64	4.89	2.18
6.	16 May 1957	5.96	6.20	10.47
7.	10 Jun 1958	4.67	10.03	5.12
8.	16 Jul 1958	.98	8.53	8.70
9.	3 Mar 1964	10.70	9.72	9.29
10.	17 Apr 1970	3.02	5.35	5.67
11.	15 Apr 1972	5.42	7.12	5.59
12.	23 Nov 1973	6.11	6.63	6.45

(1) Maximum 7-day events in May 1961 and May 1973 occurred during high Smith River conditions and are included in Table 3.
(2) Hourly precipitation recorder.
(3) Daily precipitation recorder.

d. Rainfall-Runoff Analysis:

(1) Interior Rainfall-runoff analysis is performed for each discrete event associated with blocked and unblocked gravity outlet conditions. Interior area subbasins are delineated based on hydrologic/hydraulic, flood damage, and existing and potential project locations. Runoff hydrographs are calculated from the historic rainfall patterns, adopted losses rates, unit hydrograph transforms, and base flow (including seepage conditions). The hydrographs are subsequently combined and routed throughout the interior area to the line-of-protection.

(2) A percent imperviousness adjustment is required to reflect ponding and saturated ground conditions from runoff or seepage. This adjustment is necessary for the 13 high river floods to calibrate the events and generate the appropriate volume of runoff. No adjustment is necessary to the 12 maximum 7-day storm floods associated with unblocked gravity outlet conditions.

(3) Modified Puls procedures simulated flood routings through both channel and ponding reaches. Storage-outflow data are obtained from water surface profile analyses, and area-elevation-storage data from topographic maps and surveyed sections.

e. Coincident Flood Analyses.

(1) Flood hydrographs are routed through the levee by simulating gravity outflow and/or pumping capacity associated with the exterior and interior head differential. The routings include the 13 blocked and 12 unblocked condition hydrographs. The analysis results provide peak ponding elevations adjacent to the line-of-protection.

(2) Calibration of the results is performed for the 1973 peak stage information and by data received through extensive interviews with local residents. Local residents provide data on the frequency of road overtopping, ditch and channels overflowing the banks, and drainage patterns for the flat interior area.

B2-5. Existing Without Project Conditions Analysis.

a. Existing conditions elevation-frequency relationships are developed graphically using peak elevation values determined from the interior analyses. The relationships are used to determine elevations and flood delineations associated with selected return interval events. The functions are also applied in the calculation of existing conditions expected annual damage. Table B2.3 is a tabulation of the peak interior flood elevations, for the area adjacent to the gravity outlet, for each of the 25 events analyzed.

b. Development of elevation-frequency relationships for the 12 maximum 7-day rainfall events, coinciding with low exterior (unblocked) gravity outlet conditions, is performed using Weibull's plotting positions. The peak values are arranged in descending order and plotted on probability paper using the Weibull's plotting positions. Since the data were attained from the 1948-1974 period, the denominator (N) in the Weibull plotting position equation (1/N) = 27.

c. The peak elevation-frequency relationship for the 13 high river events are similarly developed, with the exception of the plotting position for the 1973 flood event and the length of record N. The extreme flood depth and duration of this interior flood event resulted from a rare combination of long duration river flooding and corresponding extreme rainfall totals over the interior (See Table B2.1). Separate assessments resulted in an estimated .1-percent chance exceedance frequency for this event in the interior study area. Since these 13 events were the maximum for the period 1934-1975 the Weibull N value is equal to 43.

Table B2.3
Existing Conditions Interior Analysis Results
(at Gravity Outlet)
High Exterior (River) Stages

Flood Event Date	Max. Interior Water Surface Elevation (NVGD)	Weibull Plotting Position	Flood Event Date	Durations (Days) Above Gravity Outlet Closure Elevation
Mar 1973	338.2	.1*	Mar 1973	164
Mar 1945	331.3	4.5	Apr 1944	100
May 1935	331.2	6.8	Mar 1952	84
Jun 1951	330.8	9.0	May 1943	82
May 1943	330.7	11.4	Mar 1945	80
Jun 1969	330.7	13.6	Jun 1951	72
May 1947	330.4	15.9	May 1935	71
Apr 1944	330.3	18.2	May 1947	70
Mar 1960	330.3	20.5	Mar 1960	70
Mar 1952	330.2	22.7	Mar 1962	45
Mar 1948	330.0	25.0	Mar 1948	39
Mar 1961	330.0	27.3	Jun 1969	38
Mar 1962	329.6	29.5	Mar 1961	34

*Plotting position adjusted from 2.3.

Existing Conditions Interior Analysis Results
(at Gravity Outlet)
Low Exterior (River) Stages

Flood Event Date	Max. Interior Water Surface Elevation (NVGD)	Weibull Plotting Position	Flood Event Date	Durations (Days) Above Gravity Outlet Closure Elevation
May 1957	330.4	3.6	Jul 1958	29
Jul 1958	330.3	7.1	Apr 1970	28
Apr 1970	330.2	10.7	May 1957	25
Nov 1973	329.6	14.3	Apr 1972	23
Jan 1950	329.0	17.9	Nov 1973	18
Apr 1972	329.0	21.4	May 1958	18
Mar 1964	328.9	25.0	Jan 1950	18
Jan 1949	328.3	28.6	Mar 1964	16
May 1958	328.2	32.1	Jan 1949	15
Oct 1949	328.1	35.7	Aug 1952	14
Aug 1950	328.0	39.3	Aug 1950	14
Aug 1952	327.3	42.9	Oct 1949	12

d. The resulting two elevation-frequency relationships are combined by using the total probability theorem for a partial series. Table B2.4 shows the total elevation-frequency relationship for the interior ponding area adjacent to the levee at the gravity outlet.

Table B2.4
Existing Conditions Elevation-Frequency Relationship

Elevation	Probability of Interior Flooding: High River P(A)	Low River P(B)	Total Probability(1)	% Chance Exceedance Frequency
329	.600	.200	.800	80.0
330	.250	.060	.310	31.0
331	.080	.010	.090	9.0
332	.030	.001	.031	3.1
333	.016	.000	.016	1.6
334	.007	.000	.007	.7
335	.004	.000	.004	.4
336	.002	.000	.002	.2
337	.001	.000	.001	.1
338	.001	.000	.001	.1

(1) P(A) + P(B)

B2-6. Evaluation of Alternatives.

a. Feasibility assessments of flood loss reduction measures are performed for with and without existing and future project condition analyses using the basic strategy presented in paragraph 3-3. Additional gravity outlet capacity is evaluated as the initial step in the feasibility phase of the investigation. The hydrologic/hydraulic evaluations, including development of revised elevation-frequency relationships, are performed as described for existing conditions except the additional gravity outlet capacity is assumed in place. The economic evaluation shows the maximum net benefits are obtained with the addition of two 60-inch gravity outlets through the line-of-protection at the existing outlet location.

b. The existing and additional gravity outlets are adopted for the pumping capacity feasibility assessments. Evaluations of pumping plant sizes of 50-, 100-, 200-, and 500- cfs are performed for the feasibility evaluations. Maximum water surface elevations are calculated for each of the 25 historic events as described for existing conditions analyses. The economic results indicate the optimum size pumping plant to be 100 cfs. Pumping times, for operation costs analyses, are obtained by averaging the annual values for the period-of-record.

c. The feasibility assessment of other flood loss reduction measures may be performed assuming both the optimum size gravity outlet and pumping facility in place. Additional lateral channels and ditches are also required to reduce flood damage and convey flood waters to the pumping plant.

B2-7. Summary.

The multiple discrete event method provides several options of analysis. A period-of-record may be evaluated in a conventional manner using only those events that contribute to the flood problem and solution. This may significantly reduce the data processing and calibration tasks. The analysis of discrete events also makes available other single event analytical tools which typically enable evaluation of more complex hydrologic systems than those designed for period-of-record. Flood damage evaluations may be performed by event (most common for agricultural areas) or by development of exceedance frequency relationships as demonstrated in this example.

EXHIBIT B3

COINCIDENT FREQUENCY

B3-1. Purpose. This exhibit describes a case example of the coincident frequency method of performing hydrologic studies for a leveed interior area. The example emphasizes calculation concepts of the method in a feasibility study setting. Two flood seasons are analyzed to demonstrate methods of combining seasonal frequency relationships using the total probability theorem. Calculation examples are limited to existing without project conditions analysis. The reader should be familiar with the material in paragraph 4-8, Coincident Frequency Methods, prior to studying this example.

B3-2. General Study Background.

a. The Corps of Engineers is performing a planning feasibility study of the leveed interior area. The study area is the flood plain portion of an urban area along the Smith River which encompasses 5.2 square miles and is protected from direct river flooding to the Standard Project flood protection level. The study area is heavily developed with both manufacturing and commercial businesses (see Figure B3.1).

b. The interior area has a maximum water course length of 3.6 miles with an estimated imperviousness factor of 35 percent. The interior topography slopes gently to the river. An existing 54 inch circular gravity outlet passes interior flood waters through the line-of-protection for positive head differentials with the Smith River.

c. The Smith River has a drainage area of approximately 20,000 square miles above the study area. Daily stage records obtained from a nearby river gage data are available from 1929 to 1976. The mean daily discharge for the period is estimated to be 18,000 c.f.s.

d. Interior flooding typically occurs from moderate to heavy rainfall when the gravity outlet is blocked from high river stages. During low river stages the gravity outlet provides interior protection up to a one percent chance exceedance frequency event. Existing interior ponding is primarily limited to streets, parking lots, and a small amount of vacant land. Additional ponding locations are not economically and socially feasible.

B3-3. Study Strategy.

a. General Procedure. (1) A reconnaissance investigation has found that significant damage potential exists and that a feasibility study is justified to investigate alternative flood loss reduction plans. These plans include combinations of structural (gravity outlets, pumping facilities, and ditches) and nonstructural (flood proofing, relocation, regulations and flood warning-emergency preparedness) measures.

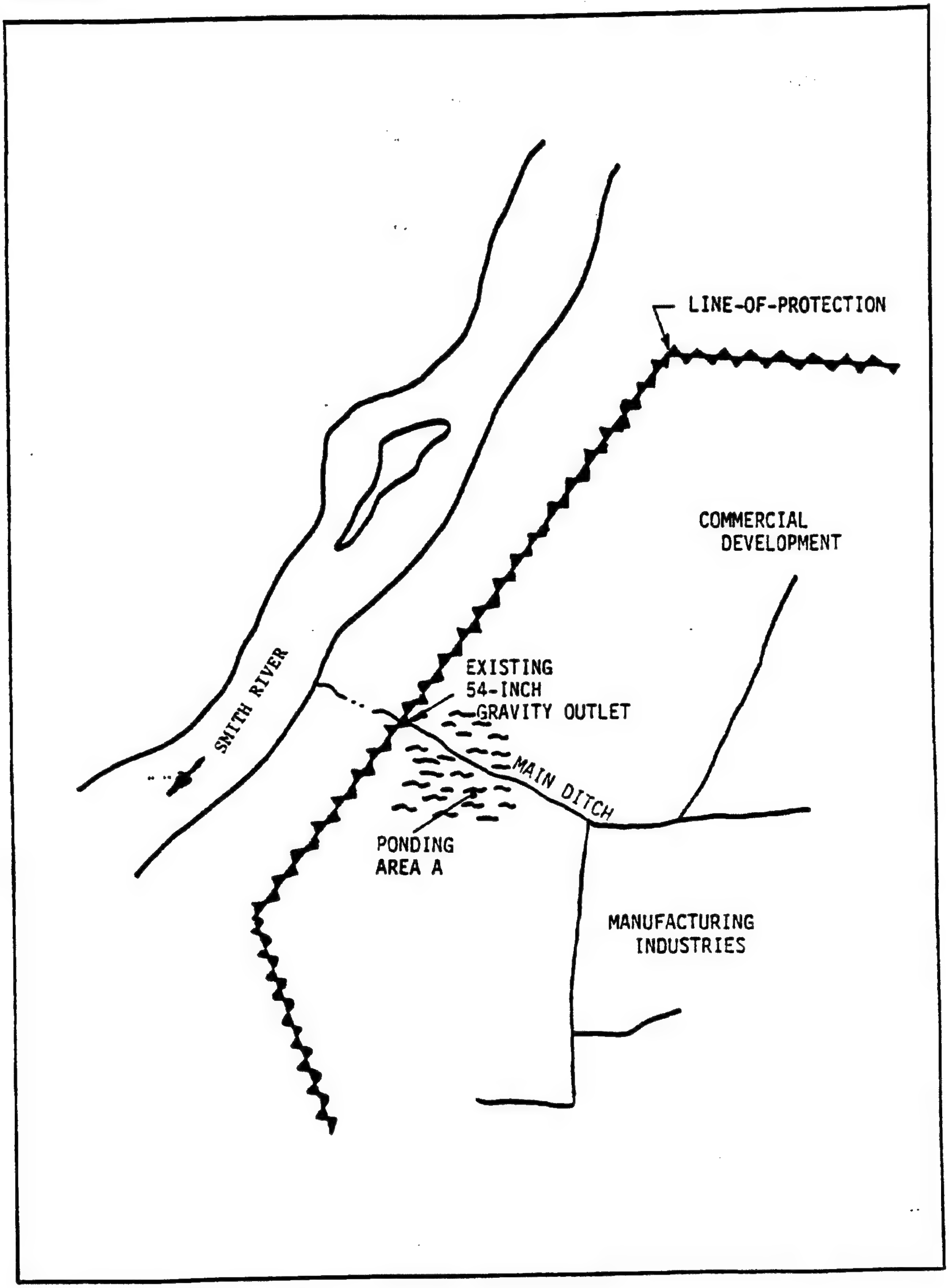


FIGURE B 3.1 Study Area Map

(2) Coincident frequency techniques are used to generate hydrologic data for flood damage evaluations, measure performance appraisals, determine the optimal sizing of plan components, and define the operation criteria of the adopted plan. Assessment of interior and exterior flooding shows a high degree of coincidence (high river stages coinciding with interior rainfall-runoff) between the river and interior flooding. However, the dependence of the events is low due to the relative size of the river drainage area with that of the interior study area (reference Table 4.1). The urban damage potential of the study area is such that detailed duration and seasonal analyses is not needed. The low-dependence of the interior and exterior events, urban flood damage potential, and simplistic interior hydrologic system make the coincident analysis procedures appropriate for this study.

(3) Adopted procedures for performing existing condition analyses are: (a) development of exterior stage data, (b) rainfall-runoff analyses of the interior areas, and (c) development of coincident stage-frequency functions. The plan formulation and evaluation strategy involves repeating (a) through (b) for each alternative analyzed. Subsequent paragraphs detail the hydrologic analysis procedures used to develop existing conditions discharge-frequency relationships. Two flood seasons are evaluated to demonstrate the process only, and are not normally required for urban damage analyses. Multiple flood season analysis may be required when flood damage is seasonally based, such as agricultural crop damage.

b. Exterior Stage-Duration Relationships. (1) Observed river daily flow estimates are used to determine the flow- and stage-duration relationships at the gage location. The data are adjusted to the nearby gravity outlet site accounting for differences in slope and rating curves between the locations. Inspection of river data indicates two distinct hydrologic seasons: (a) a flood season from April through June; and (b) a nonflood season from July through March. Figures B3.2, B3.3, and B3.4 show the annual flood season, and nonflood season stage-duration relationships for the river.

(2) Index Stage Values. Exterior index values (river elevations), required for the coincident frequency analysis, are obtained from the flow duration curve for the river. The index values represent the midpoint of the stage intervals selected for the analysis. Figures B3.3 and B3.4 show the flood season probabilities (actually percent of time exceeded) values obtained from the stage-duration relationships for each river stage used in the analysis. (NOTE: Interior analyses involving additional Smith River stage values would result in better definition of the probability intervals and more accurate results.) The nonflood season probability intervals were determined in a similar manner but are not shown (reference Figure 4.7). Table B3.1 shows the index location and associated probability of flooding for the river.

c. Interior Rainfall-Runoff Analysis. (1) The interior analysis requires development of a series of hypothetical frequency hydrographs associated with each of the index exterior stage conditions. Rainfall-runoff parameters are defined for each interior subbasin. The frequency hydrographs are routed throughout the interior system to the gravity outlet location.

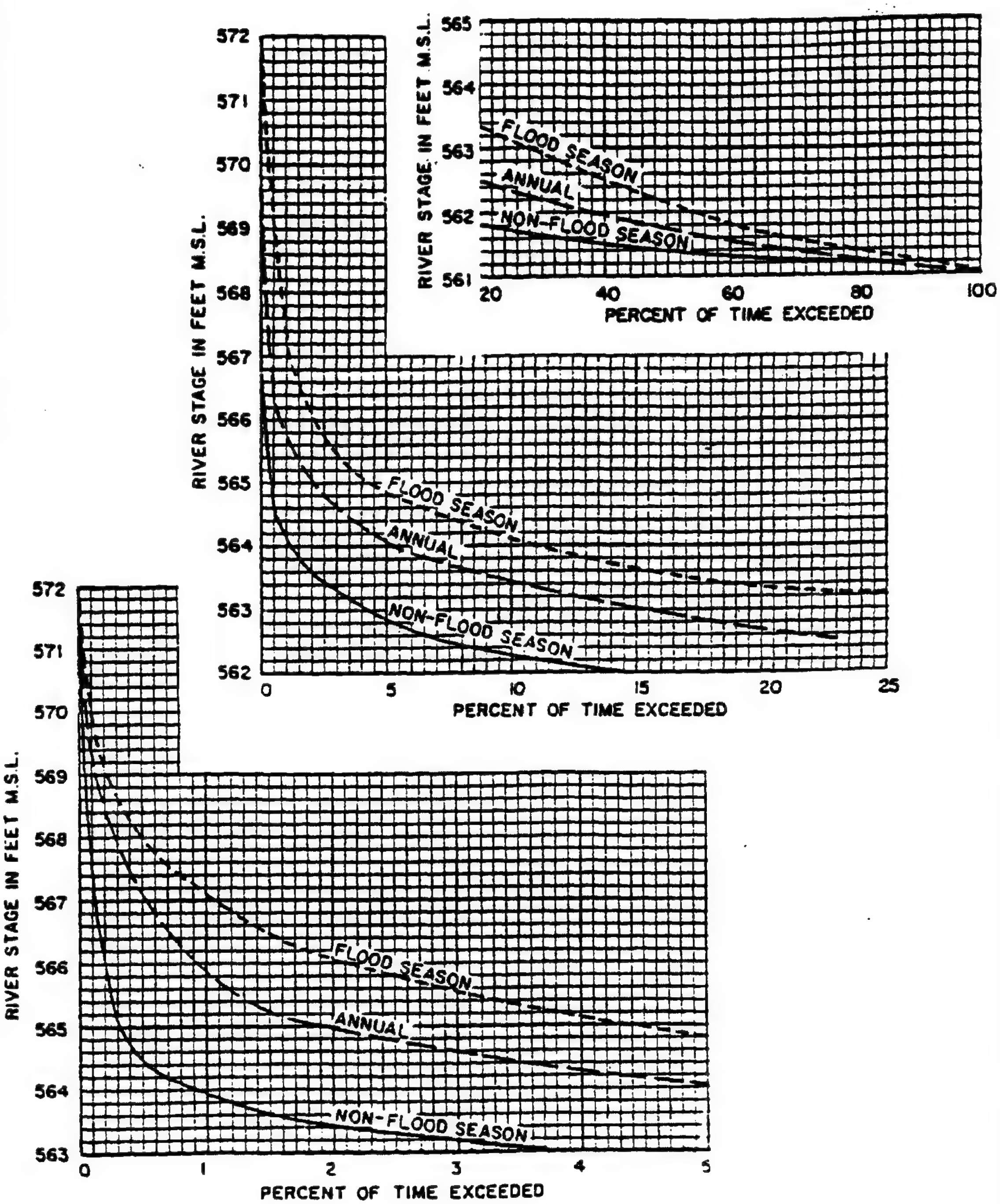


FIGURE B3.2 Seasonal Stage-Duration Relationships

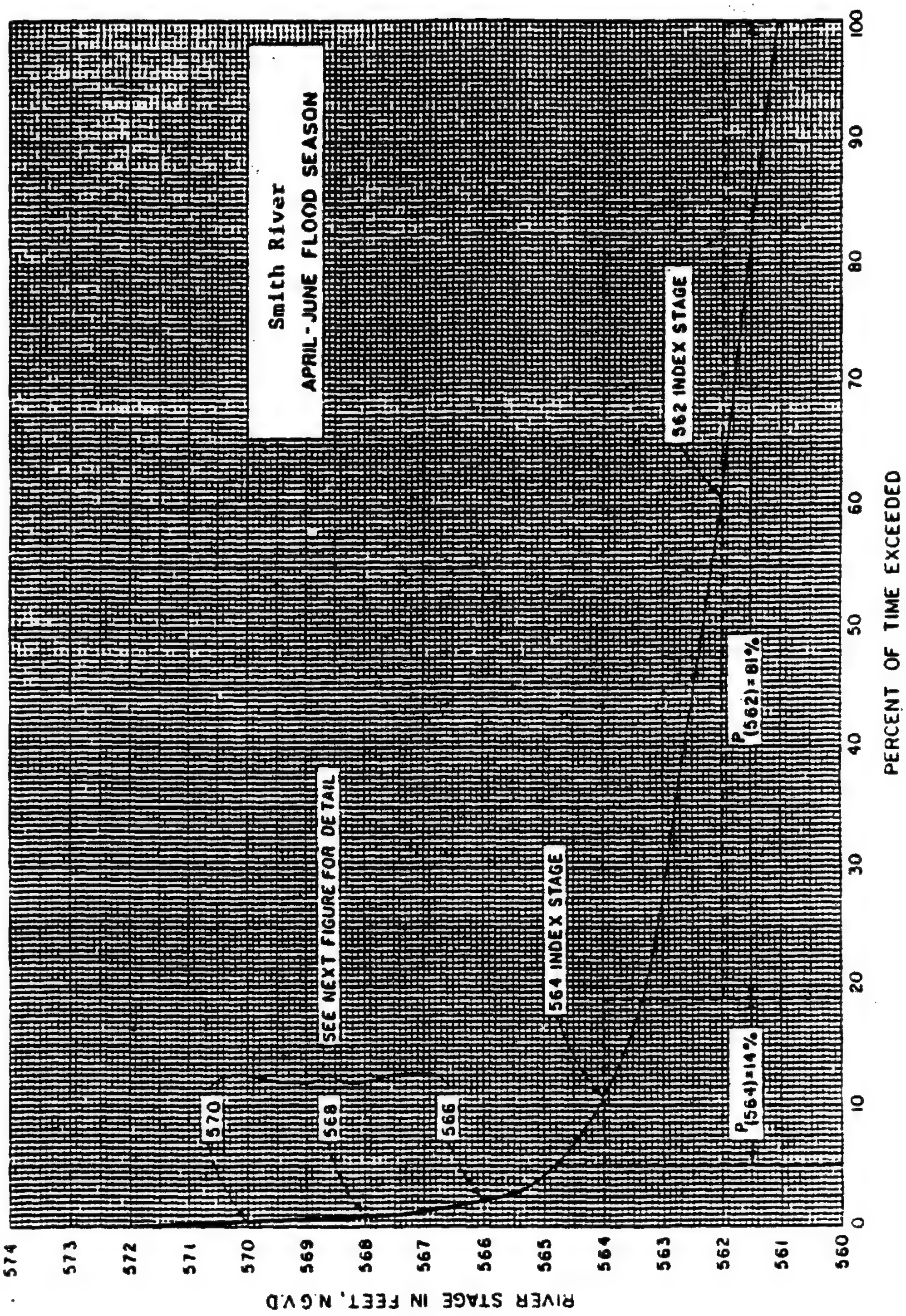


FIGURE B3.3 Flood Season Stage-Duration Relationships

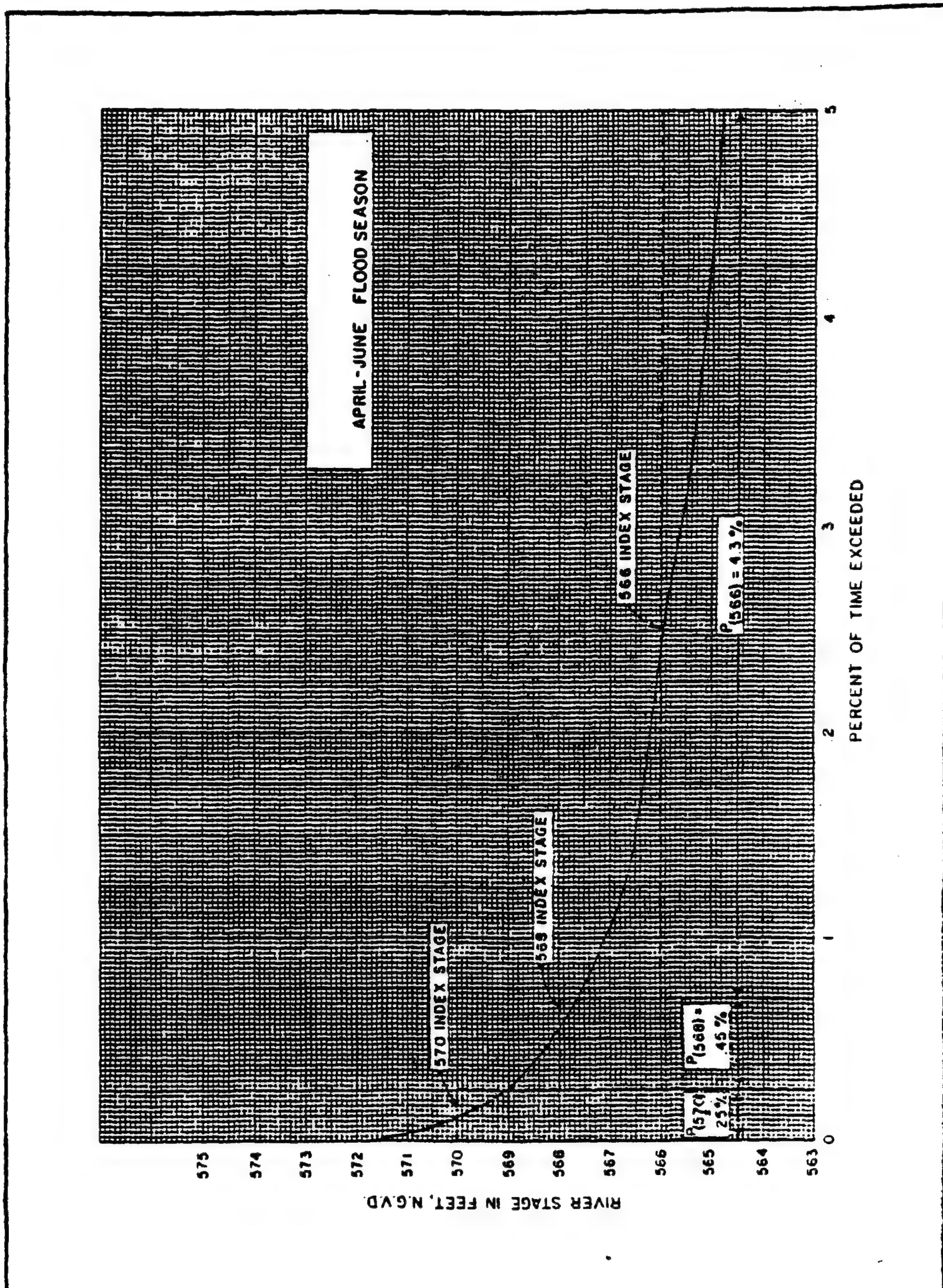


FIGURE B3.4 Flood Season Stage-Duration Relationships

(2) Rainfall Data. Hypothetical precipitation-frequency-duration annual rainfall data are used to generate interior subbasin runoff hydrographs. One hour to 10 days precipitation data are obtained from National Weather Service (NOAA) Technical publications. A 10-day rainfall duration is used to generate runoff hydrographs of appropriate volume associated with the potential long periods of high river conditions.

(3) Runoff Analysis. Rainfall excess patterns for each subbasin are calculated from hypothetical frequency storm data and loss rate parameters. The subbasin rainfall excess is transformed to runoff hydrographs at the outlet of the subbasin using a unit hydrograph. A set of interior frequency runoff events (50-, 10-, 5-, 2-, 1-, and .2 percent chance exceedance frequency assignments) are determined for each index river stage. The analyses are performed by season for existing and each modified condition. Approximated base flow and seepage inflow values are added to each event based on observed interior flow data and head differences with the river index stages, respectively.

Table B3.1
Smith River Index Stage Data

Stage Interval (Feet)	Index Stage (Feet NVGD)	Proportion of Time Stage Exceeded: Flood Season (April-June)	Proportion of Time Stage Exceeded: Nonflood Season (July-March)
558-562	560 (B_1)	.8100	.9750
562-565	564 (B_2)	.1400	.0210
565-567	566 (B_3)	.0430	.0028
567-569	568 (B_4)	.0045	.0012
569-571	570 (B_5)	.0025	.0000
		1.0000	1.0000

(4) Flood Routings. Modified Puls routing procedures are used to approximate the flood hydrograph attenuation that occurs through the conveyance and natural storage systems of the interior area. Gravity outflow routings are performed for positive head differentials between the interior and exterior stage levels. The resulting stage-frequency results are subsequently calibrated to observe event flood levels in the interior area.

(d) Coincident Frequency Analysis.

(1) Coincident frequency analysis is performed to determine peak interior water surface elevations associated with the river index stages. Flood probability values for Pond A (P(A)), given the probability (P(B)) of the river at a specified stage, are then calculated. The probability value P(A) is termed the conditional probability of the interior Pond A.

(2) The conditional probability values are subsequently used to develop a weighted stage-frequency function for Pond A for each season. Tables B3.2 and B3.3 show the coincident probability values, weighted probability computation procedures and values, and total stage-probability (exceedance frequency) relationships of Pond A for the flood and nonflood seasons, respectively.

(3) The composite stage-frequency relationship for both the flood and nonflood season is obtained by combining the two seasonal functions using the total probability theorem. The total probability relationship P_T for this example, a partial series, is obtained by the equation $P_T = P(1) + P(2)$, where P(1) equals the flood season stage probability and P(2) the nonflood season probability associated with the same stage. For an annual series analysis the total probability theorem equation is $P_T = P(1) + P(2) - P(1) \times P(2)$. The term $P(1) \times P(2)$ represents the joint probability of occurrences of the events. The numeric values, example computations, and the stage-frequency relationship are depicted in Table B3.4.

(4) Similar computation procedures are required to develop coincident stage-frequency functions for existing and future with and without conditions (not presented herein).

B3-4. Summary and Discussion.

a. The coincident analysis procedure described is directly applicable to areas where exterior and interior flood events are independent. It is often useful to analyze the two extreme conditions which bracket the results prior to initiating a complete coincident frequency analysis. These conditions are (1) completely blocked gravity outlets; and (2) completely open gravity outlets. The results of these basic analyses will provide insights into whether additional studies are required, the level of detail necessary for additional studies, and identify potential alternatives to investigate.

b. The frequency relationships defined by probabilities P(1) and P(2) may be either an annual or partial series. However, both frequency relationships must be the same type for the analyses.

Table B3.2

Development of Maximum Interior Water Surface Elevation - Frequency Relationships for Existing Without Project Conditions (Flood Season April - June)

Interior Pond Water Surface Elevation (A) (Feet NVGD)	Probability of Exceeding Pond "A" Given River Stage "B_i" (Conditional Probability $P_1(A/B_i)$)*					Weighted Probability for Interior POND Elevations $P_1(A)$
	River Stage $B_1 = 560$ Stage Prob. $P(B_1) = .8100$	River Stage $B_2 = 564$ Stage Prob. $P(B_2) = .1400$	River Stage $B_3 = 566$ Stage Prob. $P(B_3) = .0430$	River Stage $B_4 = 568$ Stage Prob. $P(B_4) = .0045$	River Stage $B_5 = 570$ Stage Prob. $P(B_5) = .0025$	
564	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
565	.5000	1.0000	1.0000	1.0000	1.0000	.5950
566	.1000	.4800	1.0000	1.0000	1.0000	.1982
567	.0100	.0700	1.0000	1.0000	1.0000	.0679
568	.0008	.0032	.0300	1.0000	1.0000	.0093
569	.0000	.0002	.0006	.0380	.3100	.0010
570	.0000	.0000	.0000	.0020	.2500	.0001
571	.0000	.0000	.0000	.0000	.0000	.0000

*Interior pond probability (exceedance frequency) values associated with the Smith River stages values are determined from hypothetical frequency flood event analyses of the interior for each river stage. Flood waters are routed through the line-of-protection (gravity outlet) during positive head.

NOTE: Example of weighted probability computations (Reference Figure 4.7, page 37), using interior elevation of 568, where:

$$P_1(A) = P_1(A/B_1) \times P(B_1) + P_1(A/B_2) \times P(B_2) + P_1(A/B_3) \times P(B_3) + P_1(A/B_4) \times P(B_4) + P_1(A/B_5) \times P(B_5)$$

$$= .0008(.8100) + .0032(.1400) + .0300(.0430) + 1.0000(.0045) + 1.0000(.0025)$$

$$= .0093$$

Table B3.3
Development of Maximum Interior Water Surface
Elevation - Frequency Relationships for Existing Without Project Conditions
(Nonflood Season July - March)

Interior Pond Water Surface Stage Prob. (Feet NVGD)	Probability of Exceeding Pond "A" Given River Stage "B_i" (Conditional Probability $P_1(A/B_1)$)*				Weighted Probability For Interior Pond Elevations $P_2(A)$
	River Stage $B_1 = 562$ Stage Prob. $P(B_1) = .9750$	River Stage $B_2 = 564$ Stage Prob. $P(B_2) = .0210$	River Stage $B_3 = 566$ Stage Prob. $P(B_3) = .0028$	River Stage $B_4 = 568$ Stage Prob. $(B_4) = .0012$	
564	1.0000	1.0000	1.0000	1.0000	1.0000
565	.3700	1.0000	1.0000	1.0000	.3858
566	.1200	.5400	1.0000	1.0000	.1302
567	.0150	.1700	.7000	1.0000	.0214
568	.0004	.0140	.1100	1.0000	.0022
569	.0000	.0008	.0045	.1500	.0002
570	.0000	.0002	.0004	.0060	.0000
571	.0000	.0000	.0002	.0009	.0000

*Interior pond probability (exceedance frequency) values associated with individual Smith River stage values are determined from hypothetical frequency flood event analyses of the interior for each river stage. Flood waters are routed through the line-of-protection (gravity outlet) during positive head conditions.

NOTE: Example of weighted probability computations (Reference Figure 4.7, page 37), using interior elevation of 568, where:

$$P_2(A) = P_2(A/B_1) \times P(B_1) + P_2(A/B_2) \times P(B_2) + P_2(A/B_3) \times P(B_3) + P_2(A/B_4) \times P(B_4)$$

$$= .0004(.9750) + .0140(.0003) + .1100(.0003) + 1.0000(.0012)$$

$$= .0022$$

TABLE B3.4
Existing Without Project Conditions Stage-Probability (Exceedance Frequency) for Interior Pond Elevation*

Interior Pond Elevation (A) (Feet NVGD)	Flood Season Interior Pond Elevation Prob $P_1(A)$	Nonflood Season Interior Pond Elevation Prob. $P_2(A)$	Total Probability Interior Pond Elevation Prob. $P(A)$	Percent Chance Exceedance Frequency
564	1.0000	1.0000	1.0000	100.00
565	.5950	.3858	.9808	98.10
566	.1982	.1302	.3284	32.80
567	.0679	.0214	.0893	9.00
568	.0093	.0022	.0115	1.00
569	.0010	.0002	.0012	.10
570	.0001	.0000	.0001	.01

* Example computation of total probability theorem for Pond A using water surface elevation 568, where:

$$P(A) = P_1(A) + P_2(A)$$

$$= .0093 + .0022$$

$$= .0115$$

GLOSSARY OF TERMS

Agricultural Areas. Lands intended primarily for crop production, pastures, and other similar uses, including the closely associated facilities of on-farm roads, fences, etc.

Base Conditions. The land use and related conditions expected to exist at the beginning of the first year of project operation.

Blocked Gravity Conditions. Conditions that exist when exterior stages are higher than interior stages, thus preventing flow of interior flood waters through the gravity outlets.

Coincident Probability (Frequency). Probability of flooding exceeding a given elevation based on the probability of flooding from each source of flooding.

Conditional Probability P(A/B). The probability of flooding from one source given the condition of flooding from another source.

Correlated. The degree to which flooding from one source occurs or can be predicted from flooding from another source.

Dependence. The degree to which flooding of an area from one source is related to (usually in a physical sense) flooding from another source.

Detention Storage Areas. Any low area near the inlets to gravity outlets, pumping stations, or pressure conduits used to temporarily store interior flood waters in excess of the rate at which these flows can be passed through the line-of-protection.

Discrete Events. Flood events in a series which may be considered individually since they are independent of other flood events in the series.

Diversions. Ditches or conduits designed to bypass flood waters around or away from a specific area.

Existing Conditions. The present land use and related conditions occurring under existing and authorized improvements, laws, and policies.

Exterior Stage. Water surface level on the unprotected (exterior) side of the line-of-protection.

Future Conditions. The most likely land use and related conditions expected in the future. Other conditions than those deemed the most likely may also be considered future conditions.

Gravity Outlets. Culverts, conduits, or other similar conveyance openings through the line-of-protection that permit discharge of interior floodwaters through the line-of-protection by gravity when the exterior stages are

relatively low. Gravity outlets are equipped with gates to prevent river flows from entering the protected area during time of high exterior stages.

Independence. Flooding of an area from one source is unrelated to flooding from another source.

Interception Systems. Sewers or ditches provided to connect existing sewers of channels discharge through the line-of-protection by means of gravity outlets, pumping stations, or pressure conduits.

Interior Stage. Water surface level on the protected side of the line-of-protection.

Interior System. Structural and nonstructural flood loss reduction measures located behind the line-of-protection. These measures may consist of water management measures of gravity outlets, pumping stations, interior detention storage, diversions, pressure conduits, hillside reservoirs, and facility protection measures of flood proofing, structure relocation, and development management measures of flood plain regulations, and flood emergency warning-preparedness planning measures.

Line-of-Protection. Location of levee or wall that prevents flood waters from entering an area.

National Economic Development (NED) Plan. The plan which maximizes net national economic development benefits.

Nonstructural Measures. Measures designed to reduce flood losses by implementation of facility flood proofing, raising, or relocation; and development regulations and flood warning-emergency preparedness planning actions.

Pressure Conduits. Closed conduits designed to convey interior flows through the line-of-protection under internal pressure. The inlet to a pressure conduit that discharges interior flows by force of gravity must be at a higher elevation than the river stage against which it functions. Some pressure conduits may serve as discharge conduits from pumping stations.

Pumping Station. Pumps located at or near the line-of-protection to discharge interior flows over or through the levees or flood walls (or through pressure lines) when free outflow through gravity outlets is prevented by high exterior stages.

Residual Damage. Flood damage remaining after implementation of the flood loss reduction measures.

Structural Measures. Measures designed to reduce flood losses by construction of levees, gravity outlets, pumping stations, detention storage, reservoirs, and diversions.

Survey Investigations. Planning studies performed in response to specific Congressional authorization to determine the feasibility of adopting Federal projects or modifying existing projects. The report is a decision document used to determine the desireability of authorization for a Federal commitment to a project.

Tie Back Levee. Levee that extends from the river, lake, or coast to a bluff line and is part of the line-of-protection.

Urban Areas. Areas presently or expected to be developed for residential, commercial, or industrial purposes within the period considered in project formulation.